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THE PROFILES OF HIGH MASONRY DAMS.

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III.

The second modification, then, of the theoretical profile of equal resistance, consists in replacing the outer curved face by a broken one composed of two planes inclined at different angles to the horizon. The principles, however, which justify us in the use of such a modification, may be carried still further, and the inner and vertical face replaced by one almost a fac simile of the outer broken one. Indeed the only essential difference between them lies in the degree of slope which we give to their two plane surfaces. On the one side both are sloping; on the other that portion of the face from the summit of the dam to a point below, (where the pressure on each unit of surface equals the assumed limit of pressure,) the wall is vertical, and from here to the base slope outward. This latter point moreover, must be directly opposite that point on the outer face at which the two sloping lines of the profile intersect. Of a profile thus constructed, some idea may be had from the sixteenth figure. It does not present any merit either as to beauty, strength, stability or economy of material not possessed by that illustrated in Figs. 12 and 13. As to economy indeed, the amount of material consumed is if anything greater in former than in the two latter forms of dams, and it may be justly doubted whether the additional stability thus obtained, is a fair recompense for the additional outlay for material and for cutting facing stones for a third sloping face.

As to the mathematical calculations of such a profile they are rather lengthy than difficult. For the upper portion A B C D, we have already discussed at length the principles, and obtained in equations 51 to 55 the necessary formulæ. The value of A B or b is of course known, as also that of A D or a' which is assumed, and is not to be greater than λ or the greatest height we can with safety give to a wall with vertical faces. That of the lower portion C D E F, may also be conducted on the principles previously laid down, and as it necessitates several eliminations of somewhat startling length we shall consider it merely in outline. Knowing the total height of the dam, and the distance A D, we of course know D G, or the height of that portion of the dam C D E F, whose breadth of base E F, we wish to find. We also know from equations 51 and 54, the breadth D C, and projecting this on the base we at once obtain that portion

of it between G and H. What there remains to be found is G E, and H F. The former of these unknown quantities we will denote by y, and the latter by z; the breadth E F, of the base by b, the part G H, which is also equal to C D, by b'; the height D G, of the lower section of the dam by a, and that of the upper section, or A D, by a'. Returning now to the equations 15 and 16, which are the general equations of stability for a dam supporting the pressure of a head of water, we find that the three unknown quantities for which we wish to find

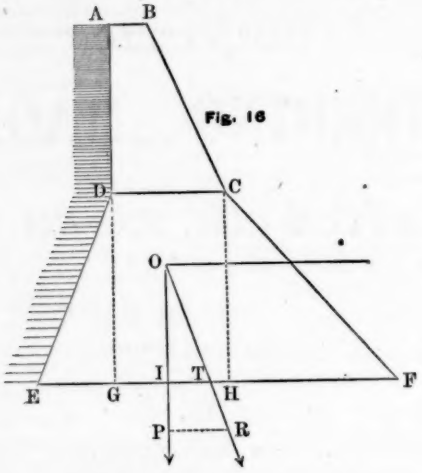


Fig. 16

values in term of known quantities we possess are u, l, and p. The value of l, or the thickness E F, of the base is when expressed in terms of the above notation.

$$l=y+b+z$$

While P is of course the area of the irregular polygon A B C F E D multiplied by the weight per unit of volume, *plus* the *vertical* component of the weight of the water resting on the sloping face D E. The area of A B C D is $\left(\frac{b+b'}{2}\right)\delta' a'$. That of C D E F is $\frac{y a \delta'}{2}+\frac{z a \delta'}{2}+b' \delta' a$. The vertical thrust of the water is by equation (1) $\left(\frac{2a'+a}{2}\right) y \delta$. The value of P, therefore, is $b' \delta' a + \frac{y a \delta'}{2}+\frac{z a \delta'}{2}+\left(\frac{b+b'}{2}\right)\delta' a'+\left(\frac{2a'+a}{2}\right) y \delta$, which reduces to the form

$$P=\frac{2 b' \delta' a+\delta' a (y+z)+2 (b+b') \delta' a'+(2 a'+a) y \delta}{2} \qquad 59.$$

Again, to find the value of u, the first step is to construct the diagram of forces, as illustrated in the figure, O P representing in direction and intensity the vertical component P, or the weight of the dam and the water, and O F the horizontal component or the outward thrust of the water behind the dam. Then will F r represent u which is clearly equal to

$$u=z+HI-Ir. \quad . \quad . \quad 60.$$

But by the two similar triangles we have, as before, $Ir=OI\times\frac{OF}{OP}$ or since $OI=\frac{a+a'}{3}$ and O F (equation 2) equals $\left(\frac{a+a'}{2}\right)^2\delta$

$$Ir=\frac{(a+a')^3 \delta}{3[2 b'\delta' a+\delta' a (y+z)+2 (b+b')\delta' a'+(2 a'+a) y \delta]}$$

H I is to be obtained in precisely the same manner as K C was obtained from Fig. 14, by expressing the relation that the moment of weight P (which includes, it is to be remembered, that of the dam and

that of the water pressing on the inclined face D E), with respect to the point F is equal to the sum of the moments of the components of this force. Obtaining these moments in the same manner as we obtained those for the equations deduced from Fig. 14, and putting them equal to the expression $P \times IF$, or $P \times (IH+z)$, we have after reduction, the equation

$$IH= \frac{12\alpha\beta+b'^2a+2ay^2+6b'ay+(ba'+3a)(y+2b')y\theta-2z^2a}{(12\alpha+b'a)+6az+6ay+12a'y\theta+6ay\theta}$$

In which α is a short expression for the area of A B C D, and β the distance from C to the point where the perpendicular of the centre of gravity of A B C D cuts C D, and this replaced in equation 60, gives for the value of u

$$u= \frac{12z(\alpha+b'a)+6za(y+z)+6zy\theta(2a'+a)+12\alpha\beta+6b^2a+2ay(y+3b')+3(2a'+a)(y+2b')y\theta-2az^2-2\theta(a'+a)^2}{12(\alpha+b'a)+6az+6ay+12a'y\theta+6ay\theta}$$

Eq. 61.

The quantities P, u and l, being thus obtained in terms of b', y, z, a and a', a substitution in equations 15 and 16, will furnish us with two equations of great length, from which, by the process of elimination, the values of x and y are readily found.

To take but one example of this form of profile, let it be required to calculate the dimensions of such a profile for a masonry dam one hundred and seventy feet in height and eighteen feet broad on top, the limit of pressure being taken at 132,000 pounds. For this purpose we have to determine beforehand the height a' of the part A B C D. This, in the present case, is taken at 80 feet, and may in all cases be assumed arbitrarily. Now, since the dam has one vertical face, we have to determine but one quantity v, or the difference between the thickness of the dam at A B and that at C D, and this value of v is readily obtained from equation 51, which, modified to suit the present notation, becomes

$$\theta a'^3-\lambda v^2-2b\lambda v+b^2a'-\lambda b^2=0 \quad . \quad 62.$$

Solving this with reference to v, we have

$$v^2+2bv=\frac{b^2a'+\theta a'^3}{\lambda}-b^2$$

$$v=\sqrt{\frac{b^2a'+\theta a'^3}{\lambda}}-b \quad . \quad . \quad . \quad 63$$

And replacing the quantities by their values, remembering that λ equals 98.4 ft., and θ (or the ratio in which the masonry is heavier than water) equals $\frac{1}{2}$, the result finally obtained is,

$$v=53.52-18 \text{ or}$$
$$b'=b+v=53.52 \text{ feet.}$$

With this value of b' we return to the equations expressing the values of x and y as deduced from equations 15 and 16, after the substitution of the value of u given in equation 61, and find that the value of $b'=x+b'+y$ is 178.42 feet.

Once more, we may carry this principle one step further and produce a profile which is little more than a modification of that given in Fig. 16. If, for instance, while preserving the same height of structure, we divide each of the three sloping faces into two parts, and give to each part thus produced a face inclined to the horizon, we shall then have a profile of such shape as that illustrated in the seventeenth figure.

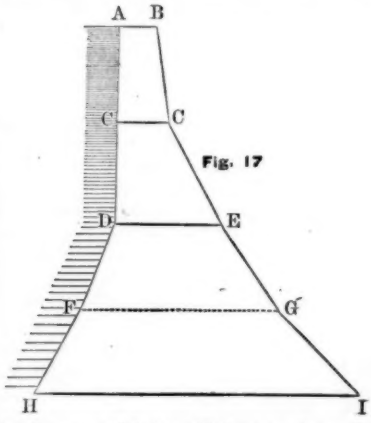


Fig. 17

A glance at this is sufficient to show that it is in reality but a compound of the two preceding profiles, and that therefore the principles to be observed in the calculation of its parts are those already discussed. The entire profile may thus be considered as divided into three pieces ;—that from A to D, in which the

inner face is vertical throughout, and the outer made up of two inclined faces, constituting a profile exactly similar in design to that of Fig. 12: that from D to F, and that from F to H, in each of which both the outer and inner faces are sloping. The first part is, therefore, to be calculated in the same manner as we would calculate the thickness of a dam having the profile of Fig. 12, and each of the two remaining portions by the equations deduced from Fig. 16. To illustrate this by a case in point, let it be required to find the thickness at various points of a masonry dam, having such a profile as that we are discussing, its thickness across the top being 18 feet, and the total height 170 feet. The first thing that claims attention is the determination of the vertical distances between the points B and C; C and E; E and G; and finally G and I. These may, of course, be chosen at pleasure, just as we may select the number of parts that each face is to be composed of, and as in the present case the dam is 170 feet high, and the outer face divided into four parts, we will for convenience divide the dam first into two equal parts, then divide the lower of these again into two equal parts, and the upper also into two, but two unequal parts. The vertical distances between the sections will then be, beginning at the bottom and going up G I = 42.5 feet; E G = 42.5 feet; C E = 45; and B C = 40 feet. Had the dam, however, been one hundred and fifty, or one hundred and eighty feet high, or indeed any other number, then the best arrangement would again have been, to make the second vertical distance—that from C to E—longer than the remaining three, so that, if the dam was one hundred and fifty feet high, the best arrangement would be B C = 30; C E = 60; and E G and G I each thirty feet; if the height had been one hundred and eighty feet, then B C = 40; C E = 50; and the others each forty-five feet. Although this arrangement may seem to be somewhat arbitrary, it is in reality based upon fixed principles, which clearly show that where such a number of divisions and such a profile as that used in the present instance are employed, the second part should be decidedly longer than either of the other three. Those portions, moreover, which are bounded on both sides by sloping faces are in almost all cases made of equal depth, nor does there seem to be any reason whatever for not adhering to this method.

With these distances thus determined, we return to equations 51 and 54, and from the first of these find the value of v, as was done for equation 63, and substituting for a' the value 40, and for b the quantity 18 feet, we have

$$v=\sqrt{\frac{12960+32000}{98.4}}-18=3.37$$

And, consequently, $b'=b+v=21.37$ feet. To find the value of b', however, it is necessary to use equations 51 and 54, from which by the common method of elimination we may find an expression

$$\theta y^3-v^2\lambda y-3by v=0$$

from which by the substitution of the proper values we obtained for a final value of b'', or the thickness of the base of this section, $b''=54.64$ feet, or $v=33.27$ feet. The next step is to find the values of x and y for the third section. As this, and also the last section have both faces sloping, by substituting the value of u given in equation 61, in equations 15 and 16, and reducing and then eliminating, we obtain two expressions for x and y, from which we derive the thickness G F = 100.36, and by a similar process find that for I H to be 152.22 feet.

It is thus apparent, that as there is almost no limit to number of sections into which a dam may, on this principle, be divided, there are a great number of different forms of profile, each of which, satisfy the conditions of stability, but vary somewhat as to economy. Theoretically the dam whose outer face consists of the greatest number of these sloping faces is the most economical, because in that case its face approaches nearest to the logarithmic curve which bounds the theoretical profile of equal resistance, and it therefore contains very little more masonry than is absolutely necessary to insure safety. In practice, however, such a dam would, in all probability prove much more costly than one consisting of a less number of section, though containing more masonry, because the angle of inclination of the different sections of the outer face

changing so frequently would greatly increase the cost of cutting the facing stone. To avoid the mechanical difficulties also likely to arise in such cases, it is sometimes well to depart altogether from this style of profile, and instead of sloping the outer and inner faces, cut them into notches or steps.

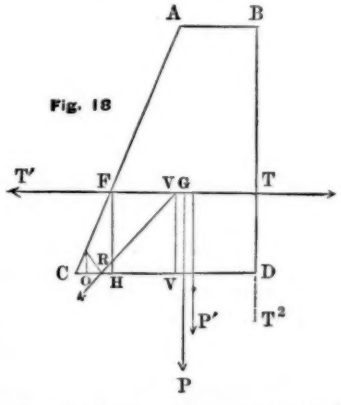
THE STEPPED PROFILE.

The stepped profile has been reserved to the last for consideration, because, while it is a natural outgrowth of the preceding modifications, it possesses many merits whose importance cannot be fully appreciated till a comparison is instituted between it and the forms just treated of. In point of simplicity of construction for instance, it would be difficult to find any design of profile that can surpass it. Wherever the faces of the dam are curved as in Fig. 9, or made up of a series of sloping surfaces of various inclination as in Figs. 12, 16 and 17, the dimensions of every facing stone that is set have to be most carefully determined beforehand by the rules of stereography, and this, when the dam is an high one and the number of stones consequently large, is of itself a work of no small difficulty. In the stepped dam however, all this is done away with, as every facing stone, (unless the dam is curved) possesses only a vertical or, if it happens to form the edge of the step, a vertical and horizontal face, and thus requires no pattern for the stone cutter. A further advantage to be derived from it, is, that it enables us to approach much nearer the curved form of profile than we can in any other profile type. Indeed, when well designed it is in reality nothing but the logarithmic curved profile cut into steps or notches, so that should we draw a continuous line through the upper edges of all the steps, or through the lower edges of their vertical faces, this line would form a logarithmic curve.

Here, as in the calculation of the previous profiles, it is quite allowable to assume arbitrarily either the breadth or height of the step and from this one determine the other. Yet it is by far the best plan to assume the vertical height of the step and calculate the breadth. For, it must be apparent, that by this method of procedure, the quantity we calculate is really the abscissa of the curve, which we lay off at regular intervals perpendicularly to the vertical axis of the dam, and in this way we are enabled to preserve very closely the logarithmic profile. The general appearance of the dam is, moreover, much more pleasing when this arrangement is observed than when we assume a constant breadth and calculate depth, because the breadth of the steps near the summit of dam are then very narrow and increase gradually as they approach the bottom, and the departure from the curve is then scarcely perceptible; but when the breadth is everywhere the same and the depth varies, the whole face of the dam has an extremely broken appearance, which is anything but agreeable.

In this profile, as in all the others, the inner face is made vertical for as great a distance as the limit of pressure will allow, and from that point down it is stepped. The outer face is likewise made vertical for a distance which depends in all cases on the thickness across the top, being as a general thing very nearly twice that dimension. In the determination of the following formulæ, the depth of the step has been assumed as the same throughout the entire dam, and the breadth has been taken as the unknown quantity. Fig. 18 then represents a portion of the profile of a dam bound by a curved or sloping face, which we wish to change into a stepped profile. A B D C represents this section, and if H F be taken as the vertical height of the step, then will C H F represent the

Fig. 18



element with which we are especially concerned, and its base C H the quantity we are in search of,—the breadth of the step. The height B D of the section we will denote by h; and the density of the masonry by δ'; and the greatest thickness F T or H D of the *known* element A B T D H F by t; from which three quantities we may obtain an expression for the weight P, of this element, which must of course be accurately known, inasmuch as the object of making the step at this point being to lessen the amount of vertical pressure on each superficial unit, the breadth of the step will depend very largely on the weight of that portion of the dam which is above it. The weight which is plainly equal to $\left(\frac{A B+F T}{2}\right) B T \delta' + (F H \times H D)\,\delta'$ is expressed by P, while that of the element C H F is equal to $\frac{b\,a\,\delta'}{2}$, in which a is the height of the step F H, and b the breadth C H. The point of application of the thrust of the water is T situated at two-thirds the depth of immersion. T′ and T² the horizontal and vertical components respectively. Then will P represent the direction of the resultant of P and T²; V V the resultant of P, T² and the weight $\frac{a\,b\,\delta'}{2}$ of the element C H F, while the general resultant of all the forces is R. Now, in this case, as in the previous ones, the whole solution of the problem depends on finding the value of C R, or the distance from the outer edge C to the point where the resultant cuts the base, and this we will express as heretofore by the letter u. Then from the figure

$$u = C H + H V - R V \quad . \quad . \quad . \quad 64.$$

in which we know the value of C H = b, and require that of H V and R V. But $\frac{R V}{V V}$ is equal to the tangent of the angle which the general resultant R makes with the vertical, or calling this angle α then

$$\text{tan. } \alpha = \frac{R V}{V V} = \frac{T'}{P + \frac{a\,b\,\delta'}{2}}$$

$$R V = \frac{T'}{P + \frac{a\,b\,\delta'}{2}} = \frac{T'\,e}{P + \frac{a\,\delta'\,b}{2}}$$

in which e is to be understood to express the value of $V V = \frac{B D}{D T}$. The distance H V may be found from the theorem of moments, by expressing the relation that

$$H V \times \left(P + \frac{\delta'\,a\,b}{2}\right) = M - \frac{\delta' b^3 a}{6}$$

$$H V = \frac{M - \frac{\delta' b^3 a}{6}}{P + \frac{\delta' a\,b}{2}}$$

M denoting the moment of P′ with respect of H. As to C H, its value is b, the quantity we are in search of. Replacing these quantities in the equation expressive of the value of u, we have

$$u = b + \frac{\frac{M - \delta' b^3 a}{6}}{P + \frac{\delta' a\,b}{2}} - \frac{T'\,e}{P + \frac{a\,\delta'\,b}{2}}$$

which, reduced to a common denominator, becomes

$$u = \frac{6\,b\,P + 3\,b^2\,a\,\delta' + M - \delta'\,b^3\,a - 6\,T'\,e}{6\,P + 3\,\delta'\,b\,a} \qquad 65.$$

Having thus obtained an equation for the value of u, the next step is to find by means of it an expression for b the breadth of the step. For this purpose draw from R, the point at which the general resultant of all the acting forces cuts the base, a perpendicular R N to the resultant, and from N a perpendicular to the base C D, thus forming a triangle R N O. Then, since the two triangles R V V and R N O have their bases on the same right line C D, and the side V R of the one perpendicular to the side N R of the other, and the sides V V and N O parallel, the angles at V and N are equal and the triangles are similar. But by the relation existing between the sides of such similar triangles, we have the proportion

$$N O : R V :: R O : V V.$$

which gives for N O the equation

$$NO=\frac{RV\times RO}{VV}=\frac{T'f}{P+\frac{\delta' a b}{2}} \quad . \quad . \quad . \quad 66.$$

where f is the distance R O. But we have another pair of similar triangles which gives yet another value for N O, which must be deduced and made equal to that just found. These triangles are C O N and C H F, and the proportion derived from the relation of their sides is,

$$NO:CO::FH:HC \text{ or}$$
$$NO=\frac{CO\times FH}{HC}=\frac{CO\times a}{b} \quad . \quad 67.$$

Equating equations 66 and 67,

$$CO\times\frac{a}{b}=f\times\frac{T'}{P+\frac{\delta' a b}{2}}$$

$$CO:f::\frac{T'}{P+\frac{\delta' a b}{2}}:\frac{a}{b}$$

And again, since if four quantities be proportional they will be in proportion by composition and division

$$CO+f:f::\frac{a}{b}+\frac{T'}{P+\frac{\delta' a b}{2}}:\frac{a}{b}$$

and reducing,

$$f=\frac{u\frac{a}{b}}{\frac{T'}{P+\frac{\delta' a b}{2}}\times\frac{a}{b}}=\frac{u a(\delta' a b+2P)}{a(\delta' a b+2P)+2T'b} \quad 68.$$

But the condition of stability is (equation 16) expressed by the relation

$$f=\frac{2\left(P+\frac{\delta' a b}{2}\right)}{3\delta'\lambda} \text{ or } \frac{2P+\delta' b a}{3\delta'\lambda} \quad 69.$$

And equating these values given in equations 68 and 69,

$$\frac{u a(\delta' a b+2P)}{a(\delta' a b+2P)+2T' b}=\frac{2P+\delta' b a}{3\delta'\lambda}$$

Substituting for u its equivalent value as given in equation 65, and dividing both members of the resulting equation by the common factor $2P+\delta' b a$, there results

$$\delta'\lambda a(6bP'+3b^2\delta' a+6M-6T'e-\delta' b^2 a)$$
$$=a(2P'+\delta' a b+2bT')(2P'+\delta' a b)$$

Solving this with respect to $x\,b^2$, and extracting the root,

$$b=-\frac{P}{\delta'}\frac{3\lambda-\frac{2T'}{\delta' a}-2a}{2\lambda a-a^2-\frac{2T'}{\delta'}}+$$
$$\sqrt{\frac{P^2\left(3\lambda-2a-\frac{2T'}{\delta' a}\right)^2}{\delta'^2\left(a(2\lambda-a-\frac{2T'}{\delta'}\right)^2}+\frac{\frac{P^2}{\delta'^2}+3\lambda\left(\frac{T'e}{\delta'}-\frac{M}{\delta'}\right)}{2a\lambda-a^2-\frac{2T'}{\delta'}}}$$

But this is capable of being yet further reduced by dividing through by

$$\frac{3\lambda-\frac{2T'}{\delta' a}-2a}{2\lambda-a-\frac{2T'}{\delta'}}$$

to the form

$$b= \quad 70.$$
$$-\frac{P}{\delta' a}+\sqrt{\frac{P^2}{\delta'^2 a^2}+\frac{\frac{4P^2}{\delta'^2}-\lambda\left(6\frac{M}{\delta'}+\theta h^3\right)}{3\lambda a-4a^2}}$$

which is the expression for the breadth of the step. As to the meaning of the letters it may once more be stated, that P is the weight in pounds of A B D H F, and δ' the density of the masonry. The *vertical* height (F H), which we determine to give the step, is expressed by a, that of the entire dam from the top to the *base* of the step by h, and the *moment* of the weight P, with respect to the vertical F H forming the *rise* of the step by M; while by λ, we mean, as in all previous formulæ, the greatest height to which we can raise a vertical wall without the pressure per unit of surface on the base, becoming larger than the limit R′ of pressure; and by θ, the expression $\frac{\delta}{\delta'}$, or the ratio in which the density of the masonry exceeds that of water. This value of θ, is safely taken at $\frac{1}{2}$. As to the height to be given to the step, this is of course to be assumed at pleasure, but the most pleasing effect is produced when it is taken at six or seven feet, for then, even in dams of one

hundred and sixty feet in height, constructed of the heaviest stone, the breadth of the step will rarely at any point be materially greater than the rise. The point on the outer face at which the first step should begin, or in other words the distance A B, in Fig. 19, is determined, as in the other instances, by the

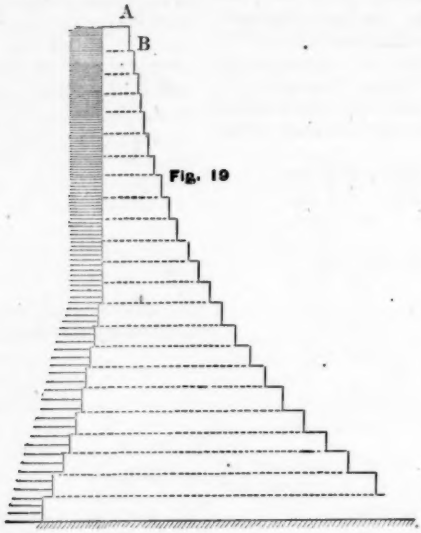


Fig. 19

relation which the breadth on top bears to the height. If the thickness t, across the summit be assumed then

$$a=\sqrt{\frac{3\,t^2}{\theta}+\frac{4\,t^4}{\theta^2\lambda^2}}-\frac{2\,t^2}{\theta\lambda}$$

but if the height a be assumed the proper thickness is to be had from the equation,

$$t=a\sqrt{\frac{\theta\lambda}{3\lambda-4a}}$$

When that point on the inner face is reached, at which it becomes necessary to begin stepping, the breadths b and b', of the outer and inner steps respectively, may be had by substituting the value of a, in equations 15 and 16, and from the two resulting equations, finding by elimination two expressions for b and b'. This calculation may, however, be avoided, and considerable expense for cutting facing stone saved, by making the inner face vertical from top to bottom. Indeed the matter of expense for dressing stone is, perhaps, the most serious objection to the stepped profile, as it is necessary to dress both faces of the step.

As regards the use of the formulæ for this form of profile, it is to be borne in mind, that P includes the weight of the water as well as the weight of the masonry, so that in determining the breadth of the fourth step, the weight of the three columns of water resting, one on the first, one on the second and one on the third step, is to be added to the pressure of the masonry. The pressure of the water is readily obtained from equation 1.

The principles that have now been established in connection with the four types of profiles treated of, are all that are required to calculate the parts of any profile that is ever likely to arise in practice. They have, moreover, been determined without regard to the length of the dam, so that the structure will be one of equal resistance, and withstand the thrust of the water solely by its own weight. There is, therefore, no valid reason why a dam constructed with a profile of equal resistance should be curved into the form of an arch, and this holds good, whether it be high or low, whether it obstructs a broad valley or a narrow one. The only thing that

can be accomplished by curving a dam, is to relieve it from severe strains, by transmitting as large a part of the thrust to the sides of the valley, but where the profile is such that the dam is everywhere equally strong, and equally capable of resisting by its own weight the severest strain it is ever subjected to, there is surely nothing to be gained by increasing its length in order to transmit this thrust laterally to the sides of the valley. It is true that in deep and narrow valleys, some saving of material may be affected by curving the dam, which being thus relieved from a goodly portion of the thrust, may be diminished in thickness. But in long dams, it is an open question whether the saving thus affected is not more than balanced by the increased length.

One other matter which deserves the most careful attention, and which indeed unless it is carefully attended to will render the very best profile of no account, it is the binding of the stones, and the character of the inner filling. As to the bond, it is undoubtedly the wisest plan if the dam is to resist a great pressure, to *avoid* laying the stones in horizontal courses wherever such a thing is practicable, and to place *binders* in every possible direction. For assuredly, if it is necessary for the stability of all walls bearing a vertical load, that there should be no continuous joints in the direction of the pressure, it is just as important that a dam should have no *continuous horizontal joints*, because in the case of such structures almost every ounce of thrust they have to resist is horizontal, and thus exactly coincides with the joints. If the dam is *curved*, then this matter of broken horizontal joints is not of such *vital* importance, because no layer can then slide until some one of the stones has been crushed, yet even here it cannot be too rigidly adhered to. By a strange inconsistency on the part of engineers, we often see this matter both regarded and disregarded in the same dam. Many structures of this class could be named, in which the rock foundation is stepped with the utmost care to preclude any possibility of sliding where sliding is of all places the least likely to occur, while the courses from the foundation to the top are laid with the most perfect kind of horizontal joints.

The filling again must not be of too different a character from the facing. Where masonry consists of dressed stone and rubble work, the amount of settling is so different in each case that nothing like a bond can be preserved. The affect of such settling, we constantly see illustrated in the most striking way in canal locks. As is well known these are generally cut stone facings with rubble backing, but the latter settling more than the former become detached from the facings, when the water penetrating between the two kinds of masonry, the cut stone facings fall with the first frost. A good filling is that made of large rough blocks of stone, set at regular intervals apart, (the distance increasing as the top is approached) and the spaces between and over them filled in with beton of the first quality, a method, we believe, lately adopted in the construction of one of the Croton dams in this state. But perhaps a yet better one is to replace the beton by the French mixture known as *beton coignet*. Both of these fillings, however, are good, as when well rammed, they form a close connection with the facing stones, and do away entirely with joints of any kind.

A METHOD OF ANGULAR CROSS-SECTIONING.*

By R. BELL, C. E.

In constructing railroads, canals and other works requiring the moving of earth and rock, it is necessary, for the purpose of computing the quantities of material moved during the process of construction, that the engineer should have an intimate knowledge of the ground on the line of the work. This is obtained by means of cross-levels taken at right angles to the reference line of

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the work at every station, and at such points between stations as the irregularity of the ground may render them necessary. This work in engineering parlance is cross-sectioning. The method herein described is a special application of the system of angular leveling. It can be used to great advantage in obtaining cross-sections of rock cliffs, steep side-hills, and rough irregular ground in general where it may be impossible to follow the ordinary operations with the *Y* level or the level straight-edge, or where the notes taken by those methods are untrustworthy, because of the difficulty of making accurate horizontal and vertical measurements. I have found it extremely useful and economical in obtaining accurate cross sections of rock cliffs with perpendicular faces and overhanging ledges ; where accurate sections are rarely obtained by means of the methods in common use, and where there is really the greatest need of them, because of the high prices usually paid for excavating and moving rock.

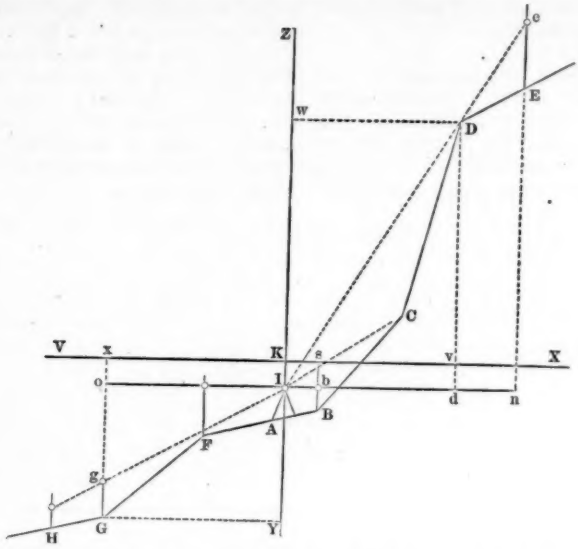
The requirements for the proper carrying on of the field work are as follows : a transitman who directs the work ; two rodmen ; a transit with level on telescope and vertical circle ; a tape, divided into feet and tenths, to measure 100 feet ; and a plain rod 14 or 16 feet long. A telescope with level attachment is required so that the transit may be used as a leveling instrument. The vertical circle is needed for the purpose of measuring angles in the vertical plane of the cross-section. One of the rodmen acts as a tapeman, while the other is carrying the rod ; and as the rod work is apt to be fatiguing, it is best to have them alternate at it about every second cross-section. When it is necessary to measure distances greater than 100 feet, or the length of the tape, it is best to use a line made of the flat steel wire which is used in the manufacture of hoop-skirts. At one end of the line there should be a ring securely fastened, and at every 10 feet there should be soldered a small piece of thin brass which has stamped on it the distance in feet from the ring end of the line. The plus distances can be measured with the tape. Three hundred feet of such a steel line can be conveniently carried on a light reel, and it will be found very useful for a variety of work.

The best rod is made of straight grain pine, and is about one and one-quarter by two and one-quarter inches in size. The lower end should be protected from wear by a suitable shoe of iron or brass. Have the rod painted white. Divide it longitudinally on one of the wide sides, beginning at the lower end, into feet, tenths, and hundredths, by black lines. The foot lines should extend across the rod, the tenth lines one-half way across, and the hundredth lines one-quarter of the way across. The foot lines should be marked with bright red figures twelve hundredths in height, and the tenth lines by black figures four hundredths in height, the middle of each figure being across the line which it designates. The hundredths can be read from the rod by the observer at the transit. The black marks and figures wear the best when they are burnt into the wood, but paint answers very well if the rod is varnished with hard drying varnish after the paint has become thoroughly dry. The rod should be fitted with a clamping target, which has fastened to its face on the horizontal centre line, and as near to the vertical centre line as it can be placed, a small hook for the purpose of attaching the ring of the tape. The rod should also be provided with a screw or hook projecting from the top, to be used for the same purpose.

These notes are more particularly descriptive of cross-sectioning on railroad work, where the centre line has been located, levels run over it and the grade line established. It is supposed, also, that the cross-sectioning and "staking out" on ordinary ground has been done, or will be done, by the method in common use, and that the angular method is to be used only for the purpose of taking sections on such ground as it is peculiarly adapted for.

Referring to the accompanying sketch, and to the field-book notes which are given below, the description of the manner of working will be readily understood.

A, in the sketch, is the point in the centre line where the cross-section is to be taken. *I* represents the transit. In the description, *I* will be used to indicate the axis of the telescope, to which



all measurements are taken. *H, G, F, B, C, D, E,* are the points in the cross-section which it is desired to note. A line connecting these points represents the surface of the ground. *V X* is the grade line of the section. The line of collimation when the telescope is level, is represented by *o In.* *Y Z* is a vertical line through A and *I.*

Column 1 of the field book has entered in it the station *A* of the centre line where the section is taken.

Column 2 contains the "height of instrument;" or, in other words, the elevation of the line of collimation, *o n* above the datum plane, when the telescope is level. The height of instrument is found by carrying the line of levels from the nearest bench-mark to the point where the instrument stands. The level notes may be kept in a compact form on the margin of the right-hand page of the field book, by adding the backsight, or the reading of the rod when it is held on the bench-mark, to the elevation of the bench-mark, then subtracting foresights and adding backsights successively; the sum after adding any backsight will be the height of instrument at that time.

Column 3 has entered in it the "grade," or the elevation of the grade line *V X*, above the datum plane, at the given station. This is taken from a list of grades which has been entered in the back part of the field book, as obtained from the profile of the located centre line.

Column 4 contains the difference between height of instrument and grade at the given station. If height of instrument is *above*, or higher than grade, the difference is marked *plus*; if height of instrument is *below*, or lower than grade, the difference is marked *minus*. This difference is constant for all the points of each cross-section, and it is used in the computations as if written in each line of the field notes.

Column 5 has entered in it the reading of the rod. This is always subtractive, and takes the minus sign.

Column 6 contains the measurement to the right or left from *I*, to the point which is noted, or to some observed point on the rod when it is held vertically upon the required point.

Column 7 contains the angle which the line of collimation makes with the horizontal, when the telescope is sighted at the point to which the measurement noted in column six is taken. It will be observed that for each station there will be as many entries in each of the columns 5, 6 and 7, as there are points noted in the cross-section at that station.

Columns 8, 9, 10 and 11, are not required for the field work entries.

All elevations, measurements, rod readings, and results of computations, are given in feet and decimals. This being understood, the words *feet* and *decimal* may be omitted in the "calling off," and for the same reason the following description will be abbreviated; an elevation such as two hundred and forty six, and forty-four one hundredths feet (246.44), being called off, or read as two, forty-six, forty-four; a rod reading, such as two feet (2.0), is called off, two, naught; and a measurement such as three and three-tenths feet (3.3), is called off as three, three.

FIELD BOOK NOTES.

1	2	3	4	5	6	7	8	9	10	11	Points.
A	246.44	248.84	−2.4	−3.1	*C*	0	−5.5	0	0	−5.5	*A*
				−2.0	*R.* 3.3	0	−4.4	0	*R.* 3.3	−4.4	*B*
				0	*R.* 13.0	+33°16′	−2.4	+7.1	*R.* 10.8	+4.7	*C*
				0	*R.* 30.5	+58°30′	−2.4	+26.0	*R.* 15.9	+23.6	*D*
				−6.6	*R.* 41.8	+58°30′	−9.0	+35.6	*R.* 21.8	+26.6	*E*
				−4.6	*L.* 7.7	0	−7.0	0	*L.* 7.7	−7.0	*F*
				−3.5	*L.* 19.4	−28°52′	−5.9	−9.4	*L.* 17.0	−15.3	*G*
				−2.0	*L.* 25.1	−28°52′	−4.4	−12.1	*L.* 22.0	−16.5	*H*

In order to explain the field work, we will suppose that the transitman—starting from the nearest bench-mark, using his transit as a leveling instrument, and following the ordinary leveling operations—has arrived at a point *A*, where a cross-section is desired, and has set his transit over a stake or peg in the centre line at that point. A sight is then taken on the centre line, and 90° are turned off, which insures the cross-section being taken at right angles with the centre line. The transitman now enters station *A* in column 1 of his field book. The height of instrument has been found to be 246.44, which is entered in column 2. Grade in column 3 is 248.84. Height of instrument is *below* grade, and the difference is entered in column 4 as —2.4. The distance from *I* to the level of the ground at *A* is found to be 3.1, which is entered in column 5 as if read from the rod through the telescope, and being a rod reading or its equivalent, it takes the minus sign. *C* in column 6 indicates that the point which is noted is in the centre line. Since there is no angle, zero is entered in column 7. The telescope is now clamped level, and a sight is taken on the rod as it is held on the point *B*. The reading *B b* is 2.0 and is entered in column 5. The tapeman, standing at the right of the transitman, calls off the distance *b I* as right 3.3, which is entered in column 6, *R* being substituted for the word right. Since the line of collimation is horizontal, there is no angle, and zero is again entered in column 7. The end of the tape is now hooked on to the screw, or hook, in the top of the rod, and the rodman pushes it up the slope to the point *C*. After indicating that the end of the rod is at the point which he desires to note, and that it is to be held there, the transitman sights at it, or at the point, and clamps the telescope. At the same time the tapeman ascertains the distance *C I* to be *R.* 13.0, and it is so entered in column 6. The sight having been taken directly at the point, there is no rod reading, and the entry in column 5 is zero. The angle of *I C* with the horizontal *In* is found to be 33° 16′, and it is entered in column 7 as + 33° 16′, the *plus* sign being placed before it because the angle is taken *above* the horizontal.

The next in order is the point *D*, which the rodman reaches either by climbing, by going around the end of the cliff, or by means of a ladder. The end of the tape being held at the point, a sight is taken to it, and the telescope being clamped as before, the angle is found to be + 58° 30′. The rod reading is zero, and the distance *D I* is 30.5 If the sight clears the edge of the cliff, the

telescope is allowed to remain clamped, and the transitman directs the rodman to go back from the face of the cliff to a point *E*, as far as he expects the excavation to extend. The rod is held in a vertical position on the point, while the transitman signals the target to be set and clamped; which being done, the reading *Ee* is given as 6.6. The rodman then holds the end of the tape at the centre of the target, while the tapeman ascertains the distance *eI* to be 41.8. These entries are made in the proper columns; the angle in column 7 being the same as that for point *D*.

If the point *E* should be so far back that the rodman cannot reach to set the target, he holds the rod in a vertical position until the transitman takes a sight on it and calls off the reading at which the target must be set. This the transitman can easily do, as there is no difficulty experienced in reading a rod, such as the one described, at a distance of 300 feet. Having the required point on the rod given him, the rodman clamps the target at it, and attaches the end of the tape to the hook on the face, then the rod being again raised to its vertical position, on the point *E*, and the transitman having signaled all right, the reading and distance are obtained as in the first case.

As all the points which are needed on the right of the centre line have now been noted, the transit is reversed and the points on the left are taken. The notes of the point *F* are taken and entered, similar to the notes of point *B*. *L*, for left, being placed before the distance in column 6, instead of *R*. The notes of the points *G* and *H* are taken and entered in a manner similar to the notes of the point *E*; with these exceptions, however, that *L* is substituted for *R* in column 6, and the *minus* sign is given to the angles in column 7. The last being for the reason that the angles are taken *below* the horizontal.

A diagram of the cross-section can be made directly from the notes thus recorded, by using a protractor and scale. But the process is slow, and the diagram is inconvenient since it involves the use of a scale whenever it is necessary to refer to it.

Cross-sections of railroad work are always plotted with reference to the grade line of the section as a base, and usually on the regulation cross-section paper. That is, paper ruled with two sets of lines at right angles with each other, every tenth line being heavier than the rest. The lines being ruled an equal distance apart, the use of a scale for the purpose of plotting the diagrams is unnecessary.

It is desirable for several reasons that the diagrams of the angular cross-sections should conform, as to method of plotting and style, with the ordinary cross-sections. A new set of notes should, therefore, be deduced from the field notes, by means of which the cross sections may be plotted on cross-section paper in the usual manner. In order to obtain such a new set of notes, it will be necessary to substitute for the polar coordinates of the field notes, a system of rectilineal coordinates, the coordinate axes of which shall be a horizontal line corresponding to the grade line of the section, and a vertical line through the point of intersection of the plane of the section and the centre line. Referring to the sketch, the horizontal coordinate axis will be the grade line *VX*, and the vertical axis will be the line *YZ* passing through *A*. If the base line *on*, of the system of polar coordinates was coincident with the grade line *VX*, the substitution would be very easy, since the vertical coordinate axis *YZ* passes through the pole *I* of the system of polar coordinates; and for a point such as *E* it would be necessary only to find the latitude *In* and the departure *ne* for the distance 41.8 in column 6 and the angle 58° 30′ in column 7; and then diminish the calculated departure by a distance equal to *Ee*, the rod reading which has been entered in column 5. But the line *on* is not coincident with *VX*, therefore it is necessary to further diminish the calculated departure by a distance equal to *IK*, which is equal to the difference between height of instrument and grade, already entered in column 4. As *VX* and *on* are never coincident, except by accident, it may be safely said that the correction of the calculated departure for the difference between height of instrument and grade will always have to be made. And as the correction for rod reading will also require to be made in a majority of cases,

the work will be simplified if these two corrective quantities are combined before the correction of the calculated departure is made. This is effected by finding and noting the *algebraic* sum of the quantities in columns 4 and 5 for each point of the cross-section. Since the vertical coordinate axis passes through *I*, and the sight and measurement are taken directly to the required point, or to a point vertically over it, the calculated latitude does not need any correction.

The general method by which the system of rectilineal coordinates may be substituted for the system of polar coordinates being understood, the manner in which the work is recorded will now be observed.

Column 8 contains the algebraic sums of the quantities in columns 4 and 5 for each point.

Column 9 contains a departure calculated from the measurement in column 6 and the angle in column 7 for each point. Each departure takes the same sign as the angle which is used in calculating it, and is governed by the sign in the same manner.

Column 10 contains a latitude calculated from the distance in column 6 and the angle in column 7 for each point. Each latitude is governed by the same letter, *R* or *L*, that governs the measurement in column 6 which is used in calculating it.

Column 11 contains the *corrected* departure for each point, *i. e.*, the algebraic sum of the quantities in columns 8 and 9.

The column of points is introduced here for the purpose of showing at a glance which point of the cross-section each line of the notes has reference to.

It will be observed that the signs plus and minus, in addition to being used in the algebraic sense, are also used to indicate that a distance or angle is taken above or below some given line or plane. In column 4 the minus sign shows that the distance is taken below grade. In column 5 the minus sign indicates that the distance is taken below the line of sight. In column 7 the plus line shows that an angle has been taken above the horizontal *o n*, and the minus sign, that the angle has been taken below the horizontal. In column 9 the plus sign indicates that the distance is to be taken above the line *o n*, and the minus sign that it is to be taken below *o n*.

The quantities in columns 10 and 11 comprise the new system of rectilineal coordinates. The letters *R* or *L* before the horizontal coordinates in column 10 indicate in which direction—right or left—from the centre line *Y Z* the distances are to be plotted. The vertical coordinates in column 11 are governed by the signs plus and minus in the manner mentioned above, which is also in accordance with general usage. The plus sign indicating that the distance is to be plotted above the grade line *V X*, and the minus sign, that the distance is to be plotted below the line *V X*.

The computations for a few points will now be given as examples. Whenever the "sum" of any quantities is referred to, the *algebraic sum* must be understood. For the point *A*, the sum in column 8, of the quantities in columns 4 and 5, is —5.5. As there is no distance in column 6, nor angle in column 7, there is neither latitude nor departure to calculate, and the entry in each of the columns 9 and 10 is zero. The sum of the quantities in columns 8 and 9 is entered as —5.5 in column 11. This is correct, as —5.5 is the sum of *A I* and *I K*. For the point *B*, the sum in column 8 of the quantities in columns 4 and 5, is —4.4. The distance *R.* 3.3 in column 6 and zero in column 7, show that the measurement was horizontal. Therefore *R.* 3.3, equal to *I b* or *K s*, is the correct latitude, and it is so entered in column 10. Since there is no angle in column 7, there is no departure to calculate for column 9, and the sum in column 11 of the quantities in columns 8 and 9 is —4.4. This is correct, as –4.4 is the sum of *b s* equal to *I K*, and *B b*. For the point *D*, the sum in column 8 of the quantities in columns 4 and 5 is —2.4, equal to *d v* or *I K*, since there is no rod reading in column 5. Referring to a traverse table, the latitude, for a distance equal to 1, corresponding to the angle 58°30′ is found to be .5225, which being multiplied by 30.5, the distance in column 6, gives 15.9, equal to *I d*, *K v* or *w D*, as the latitude. This, being governed by the same letter as the measurement in column 6, is entered in column 10 as *R.* 15.9. The departure, taken from the table, for the

same angle, is .8526 which being multiplied by 30.5 gives 26.0, equal to Iw or dD, as the calculated departure. This, taking the same sign as the angle, is entered in column 9 as + 26.0. The sum of the quantities in columns 8 and 9 is entered in column 11 as +23.6, which is correct, as it is equal to the difference between Dd and dv. For the point G, the sum in column 8 of the quantities in columns 4 and 5 is —5.9, the sum of ox equal to IK and Gg. The calculated departure in column 9 is — 9.4, equal to og. The latitude in column 10 is L 17.0, equal to Io, Kx or YG. The corrected departure in column 11 is — 15.3, equal to the sum ox, og and Gg.

It will he observed that the point A is recorded by means of a rod reading alone; the point B by a measurement and rod reading, without any angle; the point D by a measurement and angle, without any rod reading; and the point G by means of all three, angle, measurement and rod reading.

In plotting the cross-section diagrams, columns 10 and 11 of the notes are alone referred to. After fixing upon a horizontal line of the cross-section paper to represent the grade line VX, and a vertical line to represent the centre line through A, the plotting is quickly and easily done. To plot the point A for instance.—Zero in column 10 shows that the point has no latitude; therefore a measurement—from column 11—of 5.5 below the grade line and in the centre line, fixes the point. The measurements, of 3.3 to the right of the centre line, and 4.4 below the grade line fix the point B. Two measurements, 10.8 to the right of the centre line and 4.7 above the grade line, fix the point C. In a similar manner all the points are plotted, due regard being had for the significance of the letters in column 10, and the plus and minus signs in column 11.

Slope lines, showing the boundaries of excavations and embankments, can be drawn on the diagrams. The distances from the centre line to the points where the slope lines intersect the ground line, together with the distances of those points above or below grade, should be noted in the field book. Then, when the distances obtained from the diagram are measured out from the centre line on the ground, the slope stakes, with the "cuts" and "fills" marked on them, can be driven in their proper places. A "cut" will be the distance of the point above grade. A "fill" will be the distance of the point below grade. If, during the progress of the cross-sectioning, it is thought that a slope stake is likely to be required in the vicinity of a point, such as E, at the top or foot of a steep slope or cliff, it will be best, in order to obviate the necessity for a further measurement over the difficult ground, to fix the point E when it is noted in the cross-section, by driving a marked stake. The fact that such a stake is driven at that point should be noted in the field book. Then, when the proper location of the slope stake has been found on the diagram, it can be referred to the point E instead of to the centre line. In the case of a rock-cut or quarry, where it is usually impossible to excavate to an exact given line, the finished work can be cross-sectioned and plotted in the same manner as the original ground.

If it should be necessary to cross-section ground which cannot be seen from the transit when it is set in the centre line, as, for instance, ground back of E, a stout peg must be solidly driven at or near E, in the line of the section, and its elevation must be carefully obtained and recorded the same as other points of the cross-section. A stake should also be driven near G or H, so that a pole may be set there for a back sight, in case A cannot be seen from the peg. Since the elevation of the peg and its distance from the centre line can be obtained, the cross-sectioning can be continued by any method, as far back as may be necessary, the peg being used as a "change point" and point of reference for measurements. If the angular method is to be used, the peg must be driven where the transit can be set over it conveniently. Before continuing the cross-sectioning it is well to set the transit up temporarily a short distance from the change peg, and drive a second peg at the same elevation as the first and ten or twelve feet from it. Then, when the transit is set over the change peg, a rod reading on the second peg will give the exact distance from the change peg to the line of collimation. This is, of course, much more, accurate

than a tape measurement from the peg to the axis of the telescope.

If the located centre line is in a pond or stream, or any place where the transit cannot be set, an auxiliary base line may be established at a noted distance on one side, from which the cross-sections can be taken. Before the diagrams are plotted, the calculated latitudes for each cross-section must be increased or diminished by the distance from the auxiliary base line to the located centre line at that cross-section.

The rodman should carry a plummet and line for the purpose of plumbing his rod when the sight is taken at a high point upon it.

If the centre line is curved where the cross-sections are to be taken, the transitman should have the notes of the curve in his field book, so that he may be able to set plus stakes correctly, and also take the cross-sections normal to the curve. Just here the transit is very useful, as the work can be done accurately, while when cross-sectioning on a curve with the level, the setting of plus stakes and laying off of normals is a matter of some judgment and considerable guessing.

The instrumental work of the transitman is comparatively easy, so that he is able to give his attention to the proper directing of his assistants.

Having given a place to set the transit within the line of the cross-section, I think it is safe to say that the only limit to the use of the "angular method" will be the inability of the rodman to reach with the end of the rod or the tape, the point which it is desired to note. And, a rope and ladder and one or two extra assistants being provided, there are very few points that cannot be reached.

As I have not been able to profit by the experience of others in the use of this method of cross-sectioning, I do not claim that the manner of conducting the field work and recording the notes, is not capable of being improved. Indeed, I am inclined to think that at least a slight change in the arrangement of the field notes would result from my further experience.

Whilst writing these few pages I have had in view the fact that they are intended for the perusal of those who have, as yet, had but little experience in the *practice* of engineering, and for that reason I have endeavored to make as plain as possible every point of the field work and computations that might be obscure. In doing so there have undoubtedly been many needless repetitions, and many things have been mentioned which I should not have thought of touching upon if I had not kept in mind the fact—learned through many troublesome experiences—that there are many little technical points and obscurities of engineering practice which, in the nature of things, cannot be brought to the notice of students, things which become so nearly second nature to old engineers that they are not considered worthy of mention, so that the young engineer has to pick them up as best he may. This is my excuse for being apparently so prolix in the treatment of a subject so simple.

CRINOLINE FOR IRONCLADS.—Not because of the sex attributed to armored in common with all other ships, but for the same reason for which, according to the learned Knickerbocker, the maidens of Manhattan enveloped their ample figures in manifold plackets, is it proposed to encircle our ironclads with a network of iron wire, supported by booms at a distance of 22 feet, and kept rigid to below the depth of the keel by heavy weights. The danger to be guarded against is the fish-torpedo, one species of which can be unerringly propelled under water a distance of a mile, and if it then strikes the ship beneath her water-line she must inevitably sink; for it is understood that all the pumps on board a turret-ship, working at their highest pressure, would be incapable of discharging the water which would be admitted through a hole no larger than that made in the *Vanguard* by the prow of the *Iron Duke*. An experiment with this netting is about to be made on the *Thunderer*—the most costly of all ironclads—and there is just a chance that, notwithstanding the crinoline, she may be sent to join what is called our submarine fleet. The Whitehead torpedo appears to be a most effective implement of destruction; indeed, it would seem that there is no end to the "perils that environ" ironclads.

—*Iron.*

THE MARINE COMPASS—CONSIDERATIONS RELATIVE TO CERTAIN FUNDAMENTAL REQUIREMENTS OF IT, WITH SPECIAL REFERENCE TO THE CONSTRUCTION OF THE NAVY COMPASS.

By Professor B. F. GREENE, U. S. N., Superintendent of Compasses, Bureau of Navigation.

Proceedings of United States Naval Institute.

II.

I have entered somewhat more into dynamical details, especially in regard of these resistances to the motion of a compass-card, than might at first sight seem to be necessary; but, in order to form an intelligent judgment of the conditions which should control the construction of the marine compass, we must take into consideration the laws of the resistances to the card motion, and these cannot be duly appreciated without, at least, a definite recognition of all the elements of these resistances.

Now, with regard to the relation of these resistances to the sensibility of a compass, it will be evident, I think, that the resistance of the medium, however great it may be during certain stages of the motion of the card, cannot give rise to any part of the defect of sensibility; for, in the first place, in regarding this resistance as solely a direct function of the velocity, it must decrease with the velocity and completely vanish with the cessation of motion; secondly, and with still stronger reason, it should follow from the assumption that the resistance varies directly as the square of the velocity; that, as the velocity of the body diminishes in approaching its final position of rest, the resistance of the medium diminishes in the much more rapid ratio of the velocity squared; so that, with the last element of the velocity, the last element of this resistance is a quantity infinitely smaller in comparison.

Hence, it must be concluded that the resistance of the medium, whether air or liquid, has no influence whatever on the ultimate angle of set by which a compass-card deviates from a previous position of rest after being deflected from it.

It is otherwise with the friction at the pivot; for this being a constant force wholly independent of the velocity, it remains the same, during the smaller elements of the velocity, as during the most rapid motions, until it finally comes into equilibrium with the motive forces, and there results an angle of set, or defect of sensibility, which is represented by *the moment of friction divided by the product of the magnet-power and directive force.*

There may be a question whether, in addition to the friction of the cap upon the pivot, there may not be a certain amount of friction due to the action of the fluid in the cap immediately surrounding the pivot. This point is involved in some obscurity at present. It is not easy to separate a possible frictional resistance like this from what is recognized as the resistance of the medium proper; so that it is quite probable, whenever the former has an appreciable value, that it should be merged in the latter, in the results of experiments.

Consequently, the conditions most favorable to the sensibility of a compass appear to be these:

1. That the pressure of the card upon the pivot and the area of the surface in actual contact between the cap and pivot shall both be as small as possible.

2. That the material of the cap and pivot shall be as hard, as true to form, and as smoothly polished as possible; and,

3. That the magnet-power of the card shall be as great and as permanent as possible.

The pressure upon the pivot remains unchanged for the same compass-card; but both the mean radius of the rubbing surface and the co-efficient of friction are liable to increase—the first from the wear of the material and the second from the irregularities and roughness of the wear. The magnet-power is liable to decrease—in some cases very seriously

from original defects in the formation of the card-magnets, and in others from accidental causes incident to the handling of the compass on board ship.

But whatever the angle may be which represents the defect of sensibility, either at the outset or as the result of subsequent changes in the compass-condition, it is always *an error of the compass.* Moreover, it must be regarded as one of the most dangerous errors to which the compass is liable; because, whenever the actual condition of the compass is unknown, its value is as uncertain as that of the function upon which it depends; and this may vary from an extremely small quantity, when the *sensibility is practically perfect,* to a quantity as large as unity, when the *sensibility is nothing.*

In passing from the present topic, a remark may be permitted on the preceding definition of sensibility. It will hardly escape notice that the definition here given is not strictly in accord with a prevalent habit of verbal expression, not only among nautical men, but in ordinary popular language. Thus, a compass is said to possess sensibility when "it is lively," when "it moves quickly," etc., without regard, so far as I am aware, to the condition which I have regarded as essential to the idia of compass-sensibility.

Now, a compass-card, when nicely balanced at a jeweled cap upon the point of a hardened pivot, is extremely susceptible to motive influences from purely mechanical causes, independently of any magnet-power whatsoever in the card. The slightest disturbance actually applied to it may be sufficient to set it in motion. It is true that the motion will be different in certain respects when the card at the same time possesses any magnet-power. But the mere excitability of a compass-card, however great, and whether resulting in vibratory or other motions, cannot be regarded as a true or sufficient criterion of its sensibility from a magnetic point of view.

The intrinsic property of a compass-card, alike with that of a simple magnetic needle, is its tendency to return to its position of magnetic equilibrium whenever deflected from that position; and this is realized under the combined influence of the exterior directive force and its own magnet-power. If it fail in any degree to do this, its most characteristic, not to say its most useful, property is so far imperfect. The question, as it seems to me, is not whether the card is more or less excitable in its movements about its position of rest—for this may depend on several distinct circumstances—but solely whether, in whatever way done, it accomplishes unerringly, and with a nicety of precision that admits of no doubt, its prime function. When it does this—which it never can do except by accident, unless the resistances to motion are so small in comparison to the motive forces as to be uninfluential—then I think that the specific term *sensibility* is both significant and appropriate as the expression of such a fact.

III.—STEADINESS OF THE COMPASS.

A compass-card is said to be stable, or *steady,* when it maintains its position of equilibrium, under the magnetic forces which act upon it, without sensible disturbance by the various mechanical influences which are liable to be called into action on board ship. A compass may possess sufficient magnet-power and perfect sensibility, and yet be so deficient in steadiness, during the rolling, pitching, yawing of the ship, as to be practically useless. But any apparent compatibility of deficient steadiness with perfect sensibility can only exist for a very brief period; for the effect of much motion of the card must be to blunt or otherwise injure the pivot, or to wear the cap, with the inevitable consequence of increasing the friction, and thereby diminishing the sensibility.

Card-unsteadiness is a mechanical difficulty, and the remedy must be mechanical, so far as it is practicable to have one without compromising the sensibility.

There are two conditions of steadiness, which, at the outset, are always applicable to the cards alike of dry and liquid compasses. These are:

First, that the card shall have a tendency, whenever tilted to one side, to return to its position of horizontal equilibrium. This condition is satisfied by placing the centre of suspension well above the centre of gravity of the card, and also, in the case of the liquid compass, above the centre of buoyancy in the card.

Secondly, that the card shall have no tendency to rock in one direction more than in another; that is to say, no tendency to *wabble* about any of its diameters. And this condition requires that the material of the card shall be so distributed as to give equal moments of inertia about all its diameters. It is satisfied by arranging the relatively heavy card-magnets in one or more symmetrical pairs, on equal parallel chords of the card, at certain calculated distances from the centre.

But these conditions, although on the side of stability, so far as they go, and quite essential to a well-made compass-card of any kind, fall far short in practice of realizing even tolerable steadiness in the air or dry compass; for, while the card may not be liable to wabble, it is still prone to rock in every direction, and, although prevented from actually tilting over, it is liable to spin entirely round in its own plane under the influence of sharp jars or shocks.

Various remedies have been proposed at different times for this serious defect of the air compass. One of these consisted in fixing several projecting pins upon the upper surface of the card, which, by their friction against the glass cover above, might subdue excessive whirling and rocking motions, although no actual contact need exist while the card was in its more quiet and normal condition.

Another compass, well known and still in use, of a celebrated maker, has the provision of a very heavy card, weighing not much less than ten ounces, supported on a fixed spindle passing through it, with upper and lower bearings; and this arrangement, whenever its resistance to motion proves insufficient, is aided by a *friction-brake*, which may be turned on *ad libitum*, until the card becomes quite steady, as it undoubtedly should with the means at command.

The simplest and probably the best provision of this kind is that of a merely heavy card, with enlarged bearing surfaces at the pivot.

These, however, are not a tithe of the different devices which have been resorted to from time to time, as remedies for the evils of an unsteady compass. I have referred to them merely as illustrations of a kind of relief much resorted to even by intelligent navigators of the present day; and yet they certainly appear no more rational than the recourse of the less-informed skipper, whose little craft, dancing like a cockle-shell upon the waves, infects his compass with an excitement which he endeavors to allay by putting brick-dust in its cap. In principle they are the same. The remedy, so far as it proves effective, consists in the production of a moment of friction capable of counteracting the mechanical excitements to motion.

Without entering into any descriptive details, I think it may be said that the prevailing idea of these provisions is that of a heavier card, with more powerful magnets and the use of more rounded pivots. But, with the increase of pressure and bearing-surface at the pivot, there comes a proportional increase in the moment of friction; and thus, while the magnet-power is increased in a certain ratio, the moment of friction is augmented in a much higher one; so that, on the whole, there results at the outset a considerable sacrifice of sensibility, attended by a corresponding error of the compass. And this is not all, for these heavier weights develop proportionally greater wear at the pivot; and, if to this be added the possible deterioration of the magnets, it is not difficult to see that, even if the defective sensibility be tolerated at the beginning, the error from this source is liable to become so great, and withal so uncertain, as to make the advantage gained in mere steadiness (never, I believe, very satisfactory at the best) of doubtful value, in view of the possibly very serious sacrifice in precision.

If practicable, therefore, such a remedy should be found for unsteadiness of the compass-card as shall not impair its sensibility. And this we have by combining with the two preceding conditions a third, namely, *that of placing the compass-card in a liquid instead of a gaseous resisting medium.*

By the use of a liquid rather than an air medium, we gain the advantage of the greatly increased resistance due to the superior density of the former, which, for the liquid likely to be employed, would not be much less than 800 times that of the air. The law of the resistance would be the same in both.

With this provision, the more violent the impulse to motion, the more energetic the resistance; since, as the velocity of the card increases, the resistance of the medium increases in the more rapid ratio of the velocity squared, while, as already noticed, the resistance decreases in the same rapid ratio as the velocity becomes less.

This is illustrated by a glance at the two horizontal rows of figures, of which those in the upper row represent velocities, and those in the lower row the corresponding proportional resistances:

Velocities,
32, 16, 8, 4, 2, 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$

Resistances,
1024, 256, 64, 16, 4, 1, $\frac{1}{4}$, $\frac{1}{16}$, $\frac{1}{64}$, $\frac{1}{256}$, $\frac{1}{1024}$

Thus, a velocity represented by 32 encounters more than 1,000 times the resistance that a velocity of 1 encounters; while a velocity diminished to $\frac{1}{32}$ encounters a resistance of less than $\frac{1}{1000}$ of that due to a velocity represented by 1.

Hence the admirable facility with which a liquid compass may adapt itself to such opposite requirements; in one case presenting the most effective resistance for the destruction of all actual motions of the card, however great; in the other, offering the least possible obstacle to such motions, when in small arcs about the position of rest, whether in their incipient or terminal stages.

Nevertheless, the advantages even of a liquid medium are greatly enhanced by a certain auxiliary provision, of sufficient importance to be regarded as a fourth condition of steadiness, to wit, *that of the use of a buoyant skeleton-card with a minimum pressure at the pivot.*

With this provision, the resistance to circular motions is greatly increased, not only from the larger effective section of the card, but also from the larger coefficient due to its skeleton form; and, at the same time, the evil effects of the severe vertical shocks upon the pivot, experienced by the heavy disk-like cards, are greatly mitigated, in a higher proportion even than the reduction of pressure at the pivot.

Of course, the well-known advantage of the gimbal action is not to be overlooked as a fundamental condition of steadiness. But this provision is a condition of all marine compasses, besides entirely outside of the compass-bowl. Without this, or its equivalent, no other provision of compass-steadiness would be of any avail whatever, and even the existence of such an instrument as the marine compass impracticable.

I have thus presented an outline at least of the considerations which, in my judgment, should control the construction of the marine compass, upon the basis of the three fundamental properties assumed at the outset to be essential to its most perfect action on board ship.

IV.—THE NAVY COMPASS IN THE LIGHT OF THE PRECEDING REQUIREMENTS.

The Navy compass, as already intimated, has the distinctive peculiarities of a buoyant card in a liquid resisting medium; the mean density of the card being so adjusted to the density of the liquid as to produce a small *downward* pressure upon the pivot in the ordinary forms of ship and boat compasses, or a small *upward* pressure against the pivot in the special form of "tell-tale" or cabin compass. The compass-bowl is provided with a self-adjusting expansion-chamber, by means of which the bowl is kept constantly full, without the show of air-bubbles on the one hand or the development of undue pressure on the other, from changes of temperature.

The ship compass of general use has a $7\frac{1}{2}$ inch skeleton-card, with provision for one symmetrical pair of magnets, a division on the outer ring to quarter-points, and a card-circle adjusted to the ring, which is divided to half-degrees. The bowl-circle, or outer edge of the rim upon the bowl, is made rigid and turned strictly to gauge, so as to admit of the interchange, from one bowl to another, of every azimuth circle of its class. The compass is alike used in the steering binnacle or for azimuth purposes.

I shall now briefly consider, under the three general heads previously treated, how nearly this compass appears to be capable of satisfying the conditions therein set forth.

First, with respect to magnet-power.—The magnet-system of this compass consists of two equal compound magnets, inclosed in parallel tubes in the two chords of the circle, a little within the angle of 30 degrees from the parallel diameter. Each magnet is built up of 6

laminæ; each lamina being 6½ inches long, $\frac{1}{8}$ of an inch wide, and about $\frac{1}{10}$ of an inch thick. Each compound magnet weighs about 880 grains, or a little less than two ounces, with but slight variations.

The steel of which these magnets are made is that known in commerce as "Stubb's Sheet," which, from numerous experiments by Mr. E. S. Ritchie, has proved to be the best for this purpose, not only for its uniform excellence, but for its magnetic capacity in both intensity and permanence. In this Mr. Ritchie has but confirmed the conclusions of Doctor Scoresby, of thirty or more years ago, as to the superior qualities of this (English) steel for magnetic purposes.

The laminæ, having been cut to the proper size, are hardened and tempered throughout their entire length, the process being so conducted as to secure a remarkable degree of uniformity in the results. The magnetization is then effected by means of a very powerful electro-magnet to their utmost capacity. After this, the laminæ are separately tested for their relative magnet-power by a deflection-needle, and the angle of deflection marked on each; and, finally, they are laid aside for a little time in promiscuous contact. As required in the formation of card-magnets, these laminæ are next subjected to a careful scrutiny, being taken, one by one, and again tested for magnet-power; and every piece which shows any sensible falling off, as compared with the previous test, is thrown out.

Although I was hardly satisfied, a year ago, with certain details in the formation of our card-magnets, I am convinced that the present process, as just described, is substantially in accord with our best knowledge on this subject, and is destined to leave little to be desired in point of completeness and thoroughness for the end to be attained, namely, *to secure the most powerful magnets, compatibly with the condition of the greatest permanency, for given weights of scale.*

As to the actual magnet-power of the Navy compass, it was important to know how it compared with that of other well-known compasses. For the purpose of a comparison, I selected two 7½-inch cards of well known English makers, the best of their kind, and designed especially for steadiness, as "heavy-cards." One is designated as card "B, 468," the other as card "D, 305," the latter being a spindle card for double bearings. The former has two magnets, and the latter four, in symmetric pairs. Both cards belong to compasses of the collected specimens in my rooms at the Bureau of Navigation, and both appear to be in good condition; but whether either has suffered any loss in magnet-power, as compared with its original condition, I am of course unable to determine.* The Navy card is one of the recent make.

The results of these comparisons, by each of the three methods for finding the magnet-power, are given below:

COMPARATIVE MAGNET-POWER OF THREE COMPASS-CARDS.

I.—*By the method of deflections.*

Designation of compass.	Relative weights of cards.	Distances between centres.	Angle of deflection.	Relative magnet-power.	
				In units employed.	That of N. C. = 1.
	Ounces.	Inches.	Degrees.		
N. C.	8¼	28.8	7.4	3102.4	1.000
B, 468	3½	26.8	4.5	1514.6	0.488
D, 305	9¾	30.3	9.2	4504.0	1.453

The observations were taken at equal distances east and west of the needle, and the angle is the mean of the two observations. The needle was three inches long.

* These two cards have always been kept on their pivots, in free suspension, taking their respective positions of equilibrium, in a condition to gain rather than lose in magnet-power. The Navy compass-card has, on the contrary, been kept on a shelf, but with its pole toward the north.

II.—*By the method of oscillations.*

Designation of compass.	Time of oscillation.		Relative moment of inertion.		Relative magnet-power.	
	Of card solely.	With the additional weight.	In units employed.	That of N. C. = 1.	In units employed.	That of N. C. = 1.
	Seconds.	Seconds.				
N. C.	11.69	12.94	4.441	1.000	0.0325	1.000
B, 468.	10 31	12.96	1.725	0.388	0.0162	0.500
D, 305	9.79	10.82	4.520	1.018	0.0471	1.449

The respective times are means of 10 to 16 oscillations; suspension by threads without twist; in small arcs; protected from currents of air.

III.—*By the method of torsions.*

Designation of compass.	Tensions.	Angle of deflection.	Readings of torsion-circle.	Differences of readings.	Angle of torsion.	Relative magnet-power.	
						Mean torsion.	That of N. C. = 1.
	Ounces.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.
		0	328				
N. C.	12.5	90 W.	122	154	64	62.5	1.000
		90 E.	177	151	61		
		0	108				
B, 468.	11.5	90 W.	224	116	26	27.5	0.440
		90 E.	349	119	29		
		0	291 5				
D, 305.	12.0	90 W.	113.0	181.5	91.5	90.5	1.448
		90 E.	112.0	179.5	80 5		

The tensions for this method were reduced to a condition of approximate equality by the application of weights.

The results by the three methods are in quite close accord, with the exception of that for the card "B, 468," by the methods of torsions, the somewhat smaller value of which being due probably to the less favorable conditions under which the observations by torsion were made for that card.

It will thus be seen that the magnet-power of the navy-card, while somewhat more than twice that of card "B, 468," is less than that of card "D, 305," in the ratio of 1.000 to 1.450.

It will also be noticed, in comparing the oscillation-times and moments of inertia in the second and fourth columns of Table II., that a longer oscillation-time is not a certain indication of a lower magnet-power, unless due account be taken of the moment of inertia. Thus, the oscillation-time of the navy-card is about thirteen per cent. greater than that of card "B, 468," but its moment of inertia is nearly three times as great, so that the magnet-power is, on the whole, more than twice as great as that of the latter. On the other hand, as compared with the card "D, 305," the oscillation-time of the navy-card is still greater, but its moment of inertia is actually smaller, so that in this case the magnet-power is smaller, as it should be, than that of the card "D, 305."

Although, as shown by these observa-

tions, there is a good comparative degree of magnet-power in the navy-card, my principal doubt is, at present, in regard to the question whether we have yet reached the practical limit of magnetic development to which the card may be judiciously pushed. No case even of apparent deficiency in the magnet-power of this card has ever been brought to my notice; and my doubt on the point is, therefore, not based on the supposition of actual deficiency in this respect for ordinary circumstances, so much as on the conviction, heretofore expressed, that the compass-card should always possess a liberal reserve of magnet-power—up to the very limit which may be imposed by other conditions of card-construction—in order to provide for those large fluctuations in the directive force the effect of which might be to seriously diminish the moment of motive force, and thus to proportionally increase the defect of sensibility.

With respect to the question of magnetic permanency, our experience is too recent with the present process of magnet formation to permit the expression of any opinion as based upon actual results. This, however, may, I think, be said: that the recent changes in some of the details of that process are precisely such as, while obtaining a somewhat higher average of magnet-power in the magnet-piles, are well adapted to secure the most reliable state of permanency.

It should not be inferred that our previous experience has been particularly unfavorable with the results of the old process. So far as I am aware, not an instance has occurred, within several years past, of a reported discovery of any serious declension in magnet-power of the navy compass. Still, this is a kind of negative evidence, to which I am inclined to attach very little value, in the face of one positive fact to the contrary; and I hope to have the means hereafter of ascertaining the facts, on the return of our compasses to store after considerable periods of service on board ship.

In this respect, as in many others, there is an important advantage in favor of the navy compass—that the compass-card, being always delicately balanced on its pivot in the bowl, is in the best practicable condition for maintaining its magnet-power, other things remaining the same.

But, whatever may be revealed hereafter by a closer inquiry into the facts of our navy experience with the present form of compass, I am fully convinced that magnet deterioration is a much more prevalent and more serious evil than it is generally supposed to be by nautical men. I have had occasion, within a year past, to notice a number of instances of this kind, some of which were serious enough, and in one or two instances where I least suspected it, and by which I was considerably astonished.

The whole subject of the magnet-power of a marine-compass, in its twofold aspect of intensity and permanency, has appeared to me of such fundamental importance that I have determined to devote some time to its special study, with the hope that I may be able to clear up certain points not now as well established as I should be glad to have them.

Secondly, with respect to sensibility.—It will not be very difficult to understand why the navy compass should be expected to possess a high degree of sensibility.

Keeping in mind the condition already stated, that the defect of sensibility is equal to the moment of friction divided by the product of the magnet-power and directive force, let us consider the actual relations of these elements in the navy compass.

Now, as to this compass, the mean density of the submerged card admits of being so adjusted to the density of the liquid as to secure any desired buoyancy, and consequently produce any desired pressure of the card upon the pivot, however small, and whether upward or downward.

The minimum pressure at the pivot of the seven and a half inch card has thus been adjusted to about *sixty grains*, at the mean temperature of sixty degrees Fahrenheit, in order to provide for the variations of temperature and consequent changes in the density of the liquid ordinarily encountered at sea. It is necessary and sufficient that the least pressure to which it may ever be reduced shall be such as to secure actual contact at all times between the cap and the pivot; and, on the other hand, it is desirable that no greater excess of pressure

should be had, beyond the prescribed mean limit, than what is actually sufficient to satisfy the first condition.

It should be understood that these conditions of the card-pressure at the pivot are alike applicable, or nearly so, to the ordinary case of the downward pressure and to the special case of an upward pressure.

The relations of these pressures, downward and upward, to certain specified temperatures, for a liquid of normal mixture, at a pressure of 58 grains at sixty degrees, have been noted by Mr. Ritchie, as shown in the subjoined table :

Temperature of liquid	Pressure at Pivot.	
	Downward.	Upward.
Deg. Fah.	Grains.	Grains.
85	88	28
60	58	58
20	27	89
13	18	98

Again, so far as the choice of materials for the cap and pivot and the forming of the bearing-surfaces are concerned, the advantage is still with the Navy compass ; for, inasmuch as the bearing-pressure of the card is so greatly reduced, it will be allowable to use still harder materials and more sharply defined pivots than would be admissible in air compasses of the same size, whose lightest cards seldom fall below fifteen hundred grains ; and hence it follows that not only the mean radius of the bearing-surface, but the coefficient of friction, may be reduced to smaller values than they could have with the best possible form of air-compass card.

Accordingly, the moment of friction of the Navy compass is materially smaller than that of any air compass. Thus, without placing any estimate on the possible reduction of the two elements just named, the pressure alone, as compared with that of the lightest air-compass card, is not more than one twenty-fifth part, while it may be less than one sixtieth part as compared with that of the heavier cards.

And to this must be added the further advantage in favor of the Navy compass; that, in consequence of the extremely small working pressure of the card, the wear of the cap and pivot is so small, even during all the vicissitudes of the longest cruise, as not to materially increase the friction or diminish the sensibility. In some instances a perceptible wear of the agate in the cap has been observed on the return of the compasses for examination ; but in general the change is scarcely appreciable.

We have, then, in brief, two signal advantages of the Navy compass in point of sensibility : first, that of the extreme smallness of the moment of friction ; and, secondly, that of the proportionally small liability to change of that friction. And the second is scarcely inferior in importance to the first.

How much should be added, if anything, for the friction of the liquid in the cap, is a question which cannot be readily answered with the present state of our knowledge on this subject. That it must be very small, if, indeed, it be an appreciable element in the resistance of friction, appears quite certain, in view of such direct observations as I have been able to make on the sensibility of these compasses.

In order to illustrate the preceding view by the facts of experience, I shall first give the results of some recent inspection-tests for sensibility of a number of new Navy compasses received from the makers.

The test for sensibility consists in bringing the vertical cross-air of a telescope into precise coincidence with a division on the card-circle—as, for example, one of the zero-divisions ; then deflecting the card a *few* degrees* to one side by means of a small magnet, and allowing it to come to rest, to note the angle of set or defect of sensibility. The card-divisions are half-degrees ; and it is not difficult by means of the telescope to estimate tenths of a division, or twentieths of a degree, and to appreciate still smaller parts—as small even as one-sixtieth of a degree.

The tests were actually made by deflecting the card 3°, first to one side and then to the other, waiting in each case for the card to complete its vibrations and come to a perfect rest, before noting

* The *smaller* deflections are generally more severe tests than the larger ones.

the deviation of the zero-division from the cross-air. I thus obtained the following results, in an examination of 16 No. 1 or 7½-inch Navy compasses:

	Def.	Set.	
Of 12 compasses	3° E.	0°.00	Not appreciable.
	3 W.	0 .00	Not appreciable.
Of 1 compass	3 E.	0 .00 + W.	Appreciable.
	3 W.	0 .00	Not appreciable.
Of 1 compass	3 E.	0 .00	Not appreciable.
	3 W.	0 .00 + W.	Appreciable.
Of 1 compass	3 E.	0 .00 + W.	Appreciable.
	3 W.	0 .00 + E.	Appreciable.
Of 1 compass	3 E.	0 .05 W.	Error of 3′ W.
	3 W.	0 .05 W.	Error of 3′ W.

It is so seldom that any appreciable defect is observed in these tests for sensibility of the compasses that I am led to regard them, in their normal condition, as in this respect practically perfect.

I think it needs but a single observation, with the cross-hair of a telescope nicely adjusted upon a division on one of these cards, to be convinced of its exceeding delicacy of action. By observing in this manner the behaviour of a card after being deflected, as it approaches its final position of equilibrium, it will be seen to perform a series of minute oscillations about that position, so small and relatively so slow as to be scarcely appreciable by the unaided eye; suggesting most conclusively, I think, as already indicated on theoretical grounds, not only that the resistance of the medium at this stage is practically evanescent, but that the friction itself must be extremely small, in order that the moment of the motive forces acting at such small angles should be capable of overcoming it.

It might naturally be asked, after what has been said of the Navy compass, How does the test for sensibility result when applied to other compasses? In answer to such a question, I present the results of a few observations upon compasses of different makers, from the collection at the Bureau. With the exception of the three Navy compasses, they are all imported specimens of English makers; partly liquid and partly air compasses. None has ever been in service, and all are kept with the cards freely suspended upon their pivots.

In making the experiments of the zero or N point of each card was first adjusted to nice coincidence with the east side of the *lubber-line*, and the deflections were made with the aid of a small magnet.

Navy, 6½-inch, No. 4194.		D, No. 1514 (liquid).		Navy, 7½-inch, No. 6217.		Navy, 10-inch, No. 4126.		H, 6½-inch (air).		B, No. 468, card J (air).		D, No. 306 (air), 7½-inch.		W (liquid).	
Def.	Pts.	Def.	Set.	Def.	Set.	Def.	Set.	Def.	Set.	Def.	Set.	Def.	Set.	Def.	Set.
1-2 E.	Pts.	Pts.	Pts.	°	°	°	°	Pts.	Pts.	°	°	°	°	°	°
1-2 W.	0	1-2 E.	0	5 W.	0.0	6 E.	0.0	1-2 E.	3-16 E.	5 E.	1.3 E.	5 W.	0.6 E.	6 W.	5 W.
3-4 E.	0	1-2 W.	1-16 E.	5 E.	0.0	6 W.	0.0	1-2 W.	1-8 W.	5 E.	0.0	5 E.	0.6 W.	19 E.	15 E.
3-4 W.	0	1 W.	1-8 E.	10 W.	0.0	10 E.	0.0 E.	1-8 E.	1-8 E.	5 W.	1.7 E.	5 E.	0.1 W.	9 W.	6 W.
	0	1 E.	1-8 W.	10 E.	0.0	10 W.	0.0 W.	1 E.	3-16 E.	5 W.	1.7 E.	5 E.	0.3 W.		
		2 E.	1-16 W.			20 W.	0.0	1 W.	3-16 E.	*	*	5 E.	0.5 E.		
		1 E.	1-8 W.					*	*	5 E.	2.0 W.	5 W.	0.7 W.		
		1 W.	1-8 E.					1-2 W.	3-8 W.	5 E.	2.0 W.	5 W.	0.1 W.		
								1-2 E.	3-16 W.	5 W.	0.1 E.	5 W.	0.2 W.		
										5 W.	0.6 E.	5 W.	0.3 W.		
										5 E.	0.7 W.	10 E.	0.5 E.		
										5 E.	2.0 W.	10 W.	0.8 W.		
												20 E.	0.1 E.		
												20 W.	0.2 W.		
												40 E.	1.0 W.		
												45 E.	0.1 W.		
												45 W.	0.7 W.		

Those experiments which are preceded by a * were made after having readjusted the N point of the lubber-line.

It has not been my purpose, in giving these results, to suggest comparisons which should be regarded as in the least degree invidious; nothing could be further from my own taste or the temper of mind with which these or any similar inquiries should be conducted. The compasses are of excellent workmanship, as those which I have seen of the well-known London makers generally are; and their deficiencies in this respect are to be attributed to the inherent defects of construction, if, at least, the preceding views are accepted; namely, to the sensibly large moment of friction (as compared with that of the Navy compass), and in one or two instances to the added defect of insufficient magnet-power, both of which, as we have seen, concurring in the production of an angle of set, or defect of sensibility.

Thirdly, with respect to steadiness.—The Navy compass is hardly less remarkable for steadiness than for sensibility. For this there are several reasons:

First. In the elevation of its centre of card-suspension, decidedly above both the centre of gravity and centre of buoyancy of the card.

Secondly. In the distribution of its heavy weights, not concentric with the centre, in two equal parallel chords, a little within the angle of 30 degrees from the parallel diameter, thus securing nearly equal moments of inertia about all diameters of the card.

Thirdly. In the use of a liquid-resisting medium, with the advantages resulting therefrom.

Fourthly. In the use of a buoyant skeleton-card, adjusted to a very small pressure at the pivot, from which result the several advantages in favor of steadiness already enumerated under the general head.

Fifthly. In the preponderating inertia of the liquid mass over its friction against the interior surface of the bowl, in consequence of which any sudden impulse given to the latter causes it to slip over or round the liquid without communicating any sensible motion to it and through it to the card.

A remarkable illustration of the steadiness of the Navy compass came under my observation, a year or two ago, at the Messrs. Ritchie's in Brookline. One of the earliest appliances devised by Mr. Ritchie, Senior, for the practical study of the behavior of a marine compass, is a very effective arrangement for testing its steadiness. This apparatus, which was erected in the attic story of the workshop, consisted of a strong framework, with moving parts on opposite trunnions, so as to admit of giving to a projecting head-piece rolling and pitching motions, mingled with occasional severe jars and shocks of the most exaggerated kind. He called it his "model of a ship"; but a ship could hardly live in a sea that would cause such motions.

I mounted this arrangement on one occasion with Mr. Ritchie, when we had one of the Navy 7½-inch compasses and one of the 7½-inch air compasses of the best construction. The two compasses were placed side by side on the projecting head-piece, about three feet apart. The effect, as seen by us from our more elevated position, was sufficiently striking. The card of the air compass not only would roll and vibrate in the most extraordinary manner, but frequently spin round and round; while the card of the liquid-compass had hardly any appreciable motion, the only apparent motion being a slight swing from left to right, and from right to left, and even this was synchronous with the alternate motions in azimuth of the head-piece on which the compasses were placed. Although I made no measurements to strictly confirm this impression, I could hardly resist the conviction that the small apparent motion of the card was in reality due to the actual swing in azimuth of the lubber-line. It seemed to me, from such a test, that the steadiness of the liquid-compass might justly be regarded as sensibly perfect.

Before concluding my review of the Navy compass, in which I have not hesitated to set forth with some prominence its manifold advantages, I should not omit, I think, to mention its defect, not as a peculiarity of this compass, but as inherent to the construction of all liquid compasses. It is the practical difficulty in effecting readjustments of the card equilibrium, if found necessary for the correction of defective horizontality, re-

sulting from any considerable changes in the magnetic dip.

This difficulty is simply one of inconvenience in opening the bowl to gain access to the card. It is easily enough managed by a person accustomed to it, with the appliances of the workshop, but it is a rather troublesome operation under different circumstances.

At present, the only remedy is the provision previously mentioned as one of the mechanical conditions of a steady card, namely, that of elevating the centre of suspension "well above" the centre of gravity of the card. By this means, it is intended to give to the card such an excess of stability as to overcome its tendency to obey the varying vertical component of the earth's magnetic force in different magnetic latitudes. That this provision is sufficient, within moderate limits of the change of dip, to prevent any appreciable error from defective horizontality, is, I think, quite probable; but how far it may be relied on, under more extreme changes, is a question that must be settled by careful observations with the opportunities that may be furnished by practical experience. So far as I am aware, not an instance has been reported to the Bureau of Navigation, during all the Navy experience with this compass of any difficulty in this particular, or of any apprehended error from this source.

But, as remarked in another case, merely negative evidence (or, in this case, the absence of any express reference to this matter, in the reports of navigating officers) can hardly be accepted as conclusive that it is entirely safe to neglect this possible source of error when sailing in high southern latitudes.

Nevertheless, I apprehend no serious difficulty in providing a practical remedy for this trouble, should it ever be deemed necessary or expedient.

Another objection has sometimes been made to this compass, that it is inconvenient to handle, as a portable instrument, on a tripod for observations on shore. This I shall dispose of in a word by saying that I can conceive of no occasion for the use of any marine compass on shore, when a good surveying compass, costing less than a third as much, would not be greatly preferable for convenience in handling, facility of use, and precision of results.

CONCLUSION.

I had originally intended to include in this communication some remarks on the several instrumental errors to which the marine compass is liable, besides the defective sensibility already noticed—errors essentially of compass-adjustment; and, especially, to have given some account of the adjustments of the Navy compass and of the degree of precision actually attained, as shown by our recent inspection-tests; but this must be deferred to some other occasion. It may suffice to say that I believe the Navy compass is susceptible of a high degree of precision, and that it may be furnished to the service in a condition which shall be practically perfect in this respect. I have said nothing of the *azimuth-circle*, because the compass itself is what claims our first attention; it being wholly fallacious to expect reliable results with the use of an azimuth-circle, however excellent, upon a compass which is liable to serious errors of adjustment and of defective sensibility.

It has doubtless been presumed, from the general tenor of what has been said on compass sensibility, that considerable importance is attached to this as one of the instrumental errors of the compass. In reality, I believe its importance can scarcely be over estimated. The errors of adjustment, even when quite large, are at least of a fixed character, and, if once definitely ascertained, may either be disregarded in ordinary cases of setting courses and in working up, or possibly allowed for in cases of greater urgency. It is otherwise with the error from defective sensibility. This, even at the outset, may be sufficiently serious; but, whether more or less so, there can be no certainty with air compasses, however excellent in workmanship, as to the amount of this error a few weeks later after a little rough weather at sea.

It is sometimes asked, Of what use is all this refinement of an instrument (generally concluded to be incapable of precision), so long as the navigator is unable to profit by it, and when, if he could, he is well enough satisfied if he can steer his courses to the nearest quarter of a point?

To this it may be said that, if we concede the sufficiency of such steering in an open sea (although there might be some who might regard it as hardly close enough in these days of "swiftest transit by the shortest route"), how is the navigator to be certain of doing even that with a compass whose instrumental errors, unknown alike in name and amount, may be much greater than the assigned limit to his error of observation; and especially when, in addition to the assumed errors of observation and the unknwn errors of the instrument, the compass error is further complicated by the uncertainties of the variation and the deviation?

My own conviction is, as the result of considerable study of the subject, that, in view of the inevitable errors of observation to which the compass is liable under the trying circumstances of its use at sea, it should be our object, in the first place, to insure in the construction of this instrument not only its practically perfect condition when put on board ship, but its continuance sensibly in that condition during at least one cruise of the ship; and, in the second place, to facilitate the determination of the magnetic variation and compass deviation, considered as compass errors in the reduction to the meridian, and to bring the uncertainties of these determinations within such definite limits as it may be possible to assign with a sufficient knowledge of the circumstrnces of the case.

PERIODS OF TRANSITION IN ARCHITECTURAL STYLE; AND IS THE PRESENT DAY ONE?

By Mr. A. PAYNE, A. R. I. B. A.

From "The Architect."

THE question of style in architecture occupies an entirely different position in the present day from what it had ever occupied before. For instance, in the present day we may find in almost every city in Europe a street which has perhaps a Gothic church, a Greek public building, a Renaissance mansion, a Byzantine synogogue, and nineteenth century shops, all within the space of a few yards. But antiquity proves to us that an ancient Egyptian built in Egyptian, a Greek in Greek, a Gothic builder in Gothic; and why is it that we do not always build in the style of the nineteenth century? And what is the style of the nineteenth century? Why did the Romans adopt Greek architecture? Why was it abandoned by degrees from the third or fourth century? What caused so-called Gothic architecture to arise? Why did it come to a sudden stop in the sixteenth century? Why was it revived again in the nineteenth? Where are we in architecture, and whither are we going?

These are all momentous questions; and the theory which he ventured to bring forward to account for these changes was as follows:—In all ages the arts of mankind form a mirror in which we may perceive their intellectual, and sometimes even their moral development, acted upon and reacted upon by the circumstances in which they were placed. Thus, wherever a great intellectual development is formed among mankind—such a development, for example, as is produced by a new birth of religious ideas, there also will be found growing up a new style of architecture and a new civilization. In applying this theory to the history of the world, it might be said that the palmy days of Classic art were the heroic days of Greece. The Greeks possessed a religion of which a writer has said that "the life of the Deity was blended with all that exists in nature, and found its consummation in man." Every human faculty seemed by them to have been educated and carried to the very highest degree of culture, and in nothing did they achieve greater triumph than in the arts of sculpture and architecture. From the zenith of Greece a few centuries take us to another and equally extraordinary development of

Classic civilization—that of Rome—a kindred nation, springing from the same generic race, and with the same religion and the same architecture, but of a very different character. The ancient Roman despised learning and intellectual culture, being content to borrow his literature and his arts from the Greeks; he was a man of action, and took "material power" for his watchword. And is not this character exactly typified in the works left by this great people—in the fact that they had no distinct architecture of their own, but only borrowed and debased that of the Greeks, and that all their best works were done by Greek artists? By nature the Roman was not an artist, he did not believe in imagination, he was the engineer of Classic times; and his character is represented by those straight roads he has left wherever he has spread his conquests, or by those gigantic aqueducts running miles away in the broad Campagna from the walls of Rome.

In coming to the dark ages and the decline of Rome, it is observed that even a superficial glance at the writers of those times will show that, alone with the breaking up of the imperial power, men's intellectual and religious ideas were in a state of confusion, amounting to chaos. On the one hand more superstitious reverence was paid to statues, and ceremonies in connection with them, coupled with fanatic zeal against misbelievers, while on the other hand philosophic skepticism prevailed. This state of confusion was attended by a moral degeneracy, and these times were also amongst the most fatal to art and civilization; the crumbling away of the good old edifice of Classic civilization, art, and religion, and the gorgeous grandeur of Rome, in the first and second centuries, was the prelude to the general decay. No sooner has one religion become perverted or unsuited to the age, than a new form or development of truth is found gradually leavening the world, inspiring the minds of men, and spreading far and wide its life-giving stream. So it was with the rise of the Christian religion, which warmed men's hearts with a higher virtue and self-denial than was ever possessed by the ancient Roman, and a more poetic imagery than was ever known to the ancient Greek. The deeds of saints soon took the place of those of gods and heroes, and the beneficent figure of Christ blotted out all other representations of deity.

It is not usual to assign the Christian religion as the primary cause of those great architectural changes which finally transformed the Classic temple and basilica into a Gothic minster, but the researches of ancient writers seem to point clearly in this direction. Considerable astonishment would be felt on first looking through Count Vogue's excellent work on Early Christian architecture, "Syria Centrale," in the discovery of the magnitude of the changes introduced in the architecture of buildings erected for Christian use so early as the third and fourth centuries; these changes plainly foreshadowing the subsequent Mediæval developments. Count Vogue says that the churches of Central Syria were "built on the system of the Pagan basilicas of the country. The last, however, are surmounted by a cupola, and present already the form of the grand churches of Constantinople." In fact, if we carefully study the plates in Count Vogue's admirable work, and then turn to Galzenberg's Sta. Sophia, and other Byzantine examples, the connection is too obvious to be mistaken, and forms a complete chain between the Classic examples and the last named magnificent church erected by the Emperor Justinian, in the seventh century. At this time the West of Europe was overrun by hordes of barbarians. Rome was in ruins, the seat of the empire, and the chief city of the world, was Constantinople, so that we might well expect to find in it, as is the case, the links of the chain which unites Classic and Christian art. What were the causes which led to these seeds springing up in the East being transplanted to the West of Europe about the tenth and eleventh centuries, and there producing such a plentiful harvest in the Middle Ages when completely freed from their Classic progenitors? Unquestionably the Crusades. The epoch between the seventh and tenth centuries witnessed the consolidation and civilization of Western Europe through the agency of Christianity. But meanwhile a new danger appeared in the East in the triumph of Mahomed, and the splendid military achievements of his followers. Everywhere the unbelievers seemed to

triumph, and Christendom trembled for the fate of the Holy Land. Then followed the Crusades, and it is impossible not to perceive the immense impetus given about this time to the arts. At this period we can trace from existing buildings the streams of architecture as they flowed along the most used routes from Syria. Noticing the influences of this Byzantine stream as evidenced in the planting of a cathedral at Athens, and magnificent church of St. Mark at Venice, besides other minor churches, Mr. Payne remarked that Italy seemed also to catch the contagion, and to awake from her lethargy, and the Romanesque style in its more mature form arose, evincing a strong blending of the Syrian, and Eastern, and Classic elements. The style appears to have had its origin some centuries earlier at Ravenna, a seaport in close connection with the East. But in the eleventh century it gathers new impetus, and in the following century it gives birth to a host of noble examples in the northern cities of Italy. There was also a stream of this style running through the heart of Europe, nearly to the shores of the Northern Ocean. From the time of the Romans to the present, one of the great roadways between Italy and the North of Europe has been from Milan, over the Splugen Pass, to the present Coire, in Switzerland, and then down the Rhine to the German Sea. It is interesting to watch the stream of the Romanesque style running along this route, planting a little church at Coire among the mountains, a beautiful example in the Cathedral and cloisters of Zurich; and studding the banks of the Rhine with numerous examples, with the round arches and other characteristics of the Romanesque and Syrian styles, long after the surrounding countries were practising the pointed style even in its later developments. Indeed, at Aix-la-Chapelle, not far from this route, we may notice Eastern influence as early as the eighth century in the round church at Charlemagne, which is singularly like the churches of Ravenna. The same stream of Eastern ideas is perceptible on the other shores of the Mediterranean; it plants its mark in Sicily, and finds a welcome home in the South of France. Probably no country shows more completely the steps from Romano-Syrian to Northern Gothic than the South of France; and M. Viollet-le-Duc's "Dictionnaire," particularly under the article "Architecture," gives a series of examples which form a complete chain between the two styles, the author lucidly showing, step by step, how the changes took place, chiefly on account of problems to be solved in roofing over gigantic cathedrals in stone, when, after repeated trials, the pointed arch was found the only one to answer the purpose.

About the eleventh century the new style, now called Gothic, had fairly taken root in the powerful nations of England, France and Germany; and from the eleventh to the sixteenth centuries may be described as the very brightest period that has ever appeared for architecture. Let us compare the buildings erected during that period in our own land and those erected since. Look at the number of magnificent cathedrals—many of them in progress at the same time, and all of consummate art. Look at their splendid proportions, and variety of their conception, the exquisite beauty of their details; then turn to the countless abbeys and monasteries, all different from the cathedrals, and yet equally beautiful. Where can you find two alike, and where any instance of tameness or vulgarity? Turn to the other side of the page, and see what has been done since—in the three last centuries, far richer, more powerful, more scientific, and more able to build than those which went before. In our religious architecture of this age we have St. Paul's—a very noble building, though with scarcely a religious atmosphere, so to speak, about it—but the greater part of the page is blotted and smeared with an infinite number of tame and milk-and-water copies from the works of our forefathers—works which, if they could be beheld by the architects of Canterbury Cathedral or Westminster Abbey, would be enough to make them shiver in their tombs. But it may be said: "This is very bad for your theory; you claim a connection between intellectual and moral development and architecture, and yet you endeavor to show that this present age of light, which had its dawn at the Reformation and the revival of learning, cannot hold a candle in the art of architecture to the dark ages of Feudalism." But are we quite

correct in calling those the Dark Ages? The great characteristic of modern times is an immense development of material and physical science; but is it not possible that this exclusive attention to the material concerns may be a sign of the degeneracy of the age? May not this be shown by the immense superiority of the architecture of the Middle Ages over ours? For we must remember that architecture is not engineering, nor a material science, but a fine art which has its spring deep in the inner and spiritual part of our nature. But is this any reason why we should endeavor to go back again, architecturally speaking, to the Middle Ages? Surely not. In the words of Longfellow (slightly altered):

> We now restore the ancient fane,
> And tower and turret build again;
> The rest we cannot re-instate;
> Ourselves we cannot recreate,
> Nor set our souls to the same key,
> Of the remembered harmony.

Witness how rapidly the Gothic revival has run through all the changes backwards from Tudor to Early English, and after looking in vain for rest for the sole of her foot, is now either taking a dive into the abyss called "Queen Anne," or soaring aloft to woo the long-forgotten Romanesque. Witness how it chiefly obtains in the religious world—a world which, one may say, still lives or endeavors to live in the atmosphere of the Middle Ages. Witness what modifications it requires before adaptation to secular buildings. Witness how the mass of the people regard it as a thing for artists to amuse themselves with, but in which the public have no concern except to restrain its vagaries when they have to pay for them. No, if their be any truth in the theory here advanced that architecture and moral and mental development keep equal step and go hand in hand, we can as soon go back to the manners, habits and thoughts of the Middle Ages as induce the mass of the people to adopt Mediæval as national architecture. And it of course equally follows that we can as soon go back to the manners, customs and religion of ancient Rome or Greece as adopt their architecture as entirely ours in every detail.

It has been said by some that modern engineers have taken up the mantle left by our Mediæval forefathers, and in some respects this may be true; but as a rule engineers ignore the chief characteristic of architecture as a fine art. All honor to the skill and science of those men who had produced such stupendous works, and so immensely added to our convenience in this century. Nevertheless, unless constructors make beauty a *sine qua non* of their works, they are not architects properly so called. What appears to be wanted is for engineering skill and architectural love of beauty to act and react upon one another. If many architectural designs were submitted to the practical views of an engineer and then returned to their designer, no doubt much benefit would result. Looking at the architectural world, we notice confusion and conflicting ideas in modern times as to style; and looking to the religious world, we observe, as we might expect, an equal confusion. But it needs no prophet's eye to discern that out of chaotic existing elements a glorious picture may be preparing. Never before have all the lessons of the past been so completely laid before the present. Never have there been such skillful workmen, so many building materials, and such power to manipulate them. Yet something is wanting. What is that something? Firstly, a general love of beauty in everything diffused through all classes of the community; and, secondly, fresh and original thought brought to bear upon the architectural problems of the day—not too much trammeled by the past—the rejection of all architectural features not required by modern needs, and the adoption of modern building materials, such as iron, in the best manner. These are the principles which have developed the noble styles of the past, and why should they not give birth to the yet more noble styles of the future?

ACCORDING to the *Globe* a considerable saving in the cost of the fuel supply on the China and Australian stations will, probably, be effected by the introduction of Wollingong coal as a substitute for Welsh on board her Majesty's ships employed on the stations named. We hear, however, that North country coal will be used to mix with the Australian in the proportion of one-third.

THE EFFECTS OF THE SUN'S ROTATION AND THE MOON'S REVOLUTION ON THE EARTH'S MAGNETISM.

By J. ALLAN BROUN, F. R. S.

From "Nature."

When the mean horizontal force of the earth's magnetism for each day of the year has been deduced from well-corrected observations of the bifilar magneto-meter, and the results have been projected in the usual way, the curves thus obtained show successions of maxima and minima occurring in some instances at nearly equal intervals and in others abruptly and apparently without law. It has been found that these changes are experienced similarly at all stations where observatories have been placed on the earth's surface; they are therefore variations of the magnetic force of the whole earth. The results now considered, though derived from the observations at a single station, may thus be accepted as true generally for all places.

In the projection of the daily mean forces observed at Makerstoun in 1844, the first and last quarters of the year showed large oscillations of the earth's magnetic force, the maxima occurring near the times of new moon and the minima near those of full moon; the ranges of the oscillations were not equally great, and the oscillation disappeared in the months near mid-summer. The mean result for the whole year seemed to show that great changes of the earth's magnetic force were due to the moon's position relatively to the earth and sun; but no explanation could be offered for the apparent irregularities in the lunar action. Eleven years later (in 1857), while discussing observations made near the equator, I became persuaded that the variations in question were really due to the sun's rotation on his axis. The result of a re-examination of the Makerstoun observations gave a mean period of nearly twenty-six days for the most probable duration of the magnetic oscillation.

Astronemers who till then had occupied themselves with the determination of the time of the solar rotation has found for it from 27.3 to 27.7 days. It was difficult, in the face of this result, to suppose that the magnets were better acquainted with the true time of the sun's rotation than the eminent observers, who, with the best telescopes, had watched the movements of the solar spots; and it was suggested that a movement of the sun's magnetic poles might explain the difference of the periods obtained. More recently, however, it has been found that the spots give considerably different times for the sun's rotation, and especially that those nearest the solar equator indicate, as Spoerer has shown, a period of 26.3 days, thus approaching nearly to that obtained previously from the magnetic observations. Dr. Hornstein, director of the Prague Observatory, discovered, independently, nearly the same period from his observations in 1870.

There still remained for explanation the irregularities already noticed in the length and ranges of single oscillations. I, on the reconsideration of all the discussions previoulsy made by him, arrived some time ago at the conclusion that the results obtained for the solar and lunar actions did not exclude each other, but that both sun and moon were concerned in the changes of the earth's magnetic intensity; and that possibly the variations in the character of the single oscillations were due to the sun and moon sometimes acting in the same and sometimes in opposite directions; just as in the case of the oceanic tides, for which the differences would be even greater were the solar more nearly equal to the lunar action.

This conclusion is put to the test; the mean variations derived from the observations for each of two successive years are calculated for periods of 26, of 27.3, and of 29.53 days, the two latter being the times of the lunar, tropical, and synodical revolutions respectively. The variations for each of these three periods corresponding to the positions of the

moon and of a given solar meridian for each day of the year are then added together; the sums should represent the total actions of the two bodies for each day, and if no other causes are in question, they should agree with the observed variations.

I have shown that when the calculated results are projected so as to form a red curve, on the same mean line as a black curve representing the observations, the two agree very nearly with each other throughout the two years. The different durations and ranges of single oscillations, and the total disappearance of the latter in certain months, are found to be produced, as was supposed, by the greater or lesser agreement or opposition of the three actions.

These results demonstrate, I think, not only that the sun's rotation and the moon's revolutions produce variations of the earth's magnetic force, but that all the marked variations are really due to these causes.

There appears to be one exception to the generality of this conclusion, in sudden great changes, generally diminutions, of the earth's magnetism, which appear of variable magnitude and apparently at irregular intervals. I have examined these cases, and find that if a considerable diminution of intensity happen suddenly when a given solar meridian is in the same plane with the earth, that a similar sudden diminution generally occurs twenty-six days or some multiple of twenty six-days after, when the same solar meridian and the earth are again in the same plane. In one case the sudden loss of force begins five times in succession at the exact interval of twenty-six days.

If we examine these cases of successive disturbance when a given solar meridian arrives opposite the earth, we are induced to conclude either that the solar action exists only for this position, that is to say, that the earth is its cause; or that the action is continuous, but, unlike light and heat, is propagated only in one direction (or plane); or, which seems more probable, that the medium through which these actions are transmitted proceeds from the sun, is not uniformly distributed around it, nor always distributed in the same way. This idea may aid in explaining many facts in terrestrial magnetism for which hitherto no clue has existed.

We arrive then at the conclusions that the variations of the daily mean magnetic force are due to causes external to the earth, depending on the sun's and moon's motions; that all the principal variations of this force can be calculated approximately for each day in twelve months, on the hypothesis that the actions of these bodies are constant throughout the year for the same positions relative to the earth; and that the great magnetic disturbances (accompanied by the aurora borealis) are due to actions proceeding from certain parts of the sun's surface, since so many of them repeat themselves at intervals of twenty six days, when the same solar point returns opposite the earth. It appears from other investigations that the sun's rotation produces marked effects on our atmosphere.

THE COMBUSTION OF COAL GAS TO PRODUCE HEAT, AND THE THEORY OF THE STRUCTURE OF FLAMES.

By JOHN WALLACE.

From "Journal of the Society of Arts."

Wherever heat is required it is wanted in a certain definable quantity. This quantity is constant for any given purpose; that is to say, whether the object is heating a building, heating or melting metals, cooking, or any of the numberless operations to which we apply it, the same operation, however, often repeated under the same conditions, requires the same amount of heat.

The quantity of heat produced in order to perform any operation is always in excess of that actually required, because the whole of it cannot be utilized.

Radiation, convection, and absorption are all at work to carry off as much as possible, and the amount thus lost depends in a great measure on the method we adopt in applying it. This is well exemplified in the weight of coal required to evaporate 10 lbs. of water in a steam-boiler of good, or of bad construction, or in the weight of coal used in different stoves or fire-places to heat a room of a given size. The value of any material as fuel depends principally on its freedom from incombustible matter, and the facility with which it may be burnt in any desired quantity. Coal gas possesses these properties in a very high degree, and the condition in which it is supplied to consumers renders it the best kind of fuel for every domestic purpose requiring heat.

In many manufactures gas is the only fuel suitable for numerous delicate operations requiring a certain heat under perfect control; indeed, the possession of such a means of producing heat has given rise to numerous thriving industries which could not prosper without it.

Ordinary London gas requires to combine with about 6½ times its own volume of atmospheric air in order to be completely burnt. It will not combine with more, but if it gets less, then part of the gas which could not find enough of oxygen will escape only partially burnt, in a condition very injurious to health.

When completely burnt, a cubic foot of gas will produce a definite quantity of heat, and although some makers and vendors of gas apparatus claim for their goods the property of increasing the effect I have just indicated, it is no more possible to do it than to increase a pint of new milk by adding water.

The chief points to be observed in using coal gas are, consequently—1st, to burn it in the most complete manner; and 2nd, to utilize as much as possible of the heat produced.

There are two methods of burning gas to produce heat, each having its own merits. In one case the gas is divided into a number of small jets exposing a very large aggregate surface to the action of the atmosphere. In the other case air is mixed with the gas before burning, so that only a part of the total combining quantity of air has to join the gas at the surface of the flame. This allows the surface to be greatly reduced, and the bulk of the flame to be increased, and consequently renders it possible to burn a greater quantity of gas than before in a given space.

The latter method, which is due to Professor Bunsen, is the one almost invariably adopted in burning large quantities. The gas can not only be burnt in much less space than formerly, but it gives off no smoke, and consequently deposits no soot on any surface which it may be required to heat.

I light the gas issuing from a tube half-an-inch in diameter, and you see a long straggling smoky flame. As it is only by contact with the atmosphere that combustion can be supported, the gas has to expose a considerable surface to the air in order to get its supply. There is a hollow space in this flame extending to at least two-thirds of its height and full of gas which can only burn when it meets the oxygen. The sheath of flame surrounding this hollow space represents that part of the gas already under the influence of the oxygen, and the thickness of the sheath may represent the distance to which the oxygen penetrates before it is completely combined with the gas. If a vessel of water or other cool substance were placed over this flame a coating of soot would soon be deposited. But the moment I admit air to mix with the gas below the flame, the flame contracts to at least one-sixth of its previous size, the illuminating power disappears, and all the heat the large flame gave out is now produced by the smaller one. This flame deposits no soot, but on the contrary, will burn it off a coated surface.

Returning to the smoky flame, I coat a piece of tinplate with solid carbon which has suddenly been changed from the invisible and gaseous form into a wonderfully fine black powder; and now admitting the air, the flame shrinks and intensifies, the carbon is again transformed, and is now carbonic acid gas.

Bunsen, or atmospheric burners, no matter what their form may be, all possess certain essential parts in common. There is a gas-jet orifice, and, in close proximity, one or more air openings. There is a chamber where the gas

and air mix, and there is an outlet where the mixture burns.

Here is the simplest known form of Bunsen burner. It consists of a straight upright tube with a gas-jet orifice at the bottom and holes at each side of the jet, through which air is drawn by the inductive force of the gas. On removing the tube and lighting the jet the gas burns in a long pencil from the orifice, but, when the tube or mixing chamber is put on, the gas must burn at the top.

If the gas should light inside, then combustion is interfered with, and partially burnt gas begins to escape, producing that sickening smell which has brought the Bunsen burner so often into disrepute. The Patent office bears witness to scores of inventions devised to obviate this defect, and it is my purpose to exhibit to you several forms of apparatus designed to avoid this most inconvenient tendency.

I shall now direct your attention to the appearance of the flame, as it is in all cases an unfailing index of the value of the burner for practical purposes. Not only must the proper proportion of air be mixed with the gas, it must be mixed intimately, otherwise the flame will be irregular, produce a roaring noise, and be liable to light within on a slight change of pressure. The roaring appears to be caused by certain parts of the column of gas and air having explosive proportions which ignite and burn more readily than the rest. These explosions are so rapid as sometimes to produce a musical note. This irregular mixture may be cured in the common burner by lengthening the tube and by other methods.

Here is a burner one inch in diameter, with a flame which shows all the peculiarities of good combustion. The flame has a hollow space within represented by a most brilliant emerald green cone resting on the tube. Above and around this is a clear amber colored flame. The cone has a sparkling irregular surface, and the flame shows a strong disposition to "light down," indicating an imperfect mixture of air and gas in the tube. To render the admixture more complete I shall put into the tube a piece of sheet metal folded in such a manner as to divide the tube into several flat passages. The flame is now quite steady, although the air openings at the base of the tube are fully open, and the gas may be turned up and down within wide limits with perfect safety. In this case the surfaces against which the gas passes give it a rolling or eddying movement which thoroughly mixes the gas and air before they reach the flame. A mass of loosely twisted wire will produce nearly the same effect, but it reduces too much the velocity of the current.

Another, and a more complete method employed to adjust the proportion of air is exemplified in the "cam" burner.

At the base of the tube is a gas cock, having an eccentric fixed on the plug or key, which lifts the air slide in such a manner as to adjust the gas and air at one movement. The curves on the cam or eccentric are so made that on one side the maximum amount of air is admitted, producing an oxydizing flame, while on the other side the curve allows a less amount of air, producing a deoxydizing flame. By quickly reversing the cock, the air slide is closed, and pure gas burns at the top of the tube. In addition to this, the burner tube is hinged so as to incline to any angle, making on the whole a very useful laboratory burner.

To illustrate the intensity of the heat of the flame, I shall expose to it a piece of stout copper wire. It becomes rapidly red hot, then a pale golden color, and now it has fallen in molten drops into the vessel of water placed below the flame. Copper is estimated to melt at 2,245° F.

It is not always convenient to use a burner of this description, because if the pressure were to be suddenly lowered independent of the gas cock and cam, it would light down and cause the usual nuisance.

In order to have a burner which shall be absolutely safe and reliable under all variations of pressure and quality of gas, another form of burner must be used, of a class represented by the tangent burner.

It consists of a circular chamber, into which the jet of gas enters at a tangent, drawing with it the air necessary for preadmixture. The compound eddies round the chamber escaping finally at the tube a perfect mixture. A diaphragm of wire gauze below the tube prevents the flame from getting into the chamber,

and a covering of the same material protects the jet orifice of the gas.

This burner may be made of various sizes, of which I have here an example with twelve flames.

It is now time to inquire how much air is mixed with the gas previous to combustion. The Tables I. and II. contain the desired information. They were made upon Newcastle coal gas, combining with

EXPERIMENTS ON THE PROPORTION OF GAS AND AIR, MIXED PREVIOUS TO COMBUSTION, IN WALLACE'S BURNER.

TABLE I.—*Pressure of Gas and Air six-tenths of an inch.*

Experiments.	Height of Inner Cone.	Height of Outer Flame.	Volume of Gas per Hour.	Volume of Air per Hour.
	Inches.	Inches.	Cubic feet.	Cubic feet.
No. 1.....	.29	2.75	6.00	8.22
No. 2.....	1.00	2.55	6.00	6.00
No. 3.....	1.55*	3.30	5.82	3.66

TABLE II.—*Pressure of Gas and Air fifteen-tenths of an inch.*

Experiments.	Height of Inner Cone.	Height of Outer Flame.	Volume of Gas per Hour.	Volume of Air per Hour.
	Inches.	Inches.	Cubic feet.	Cubic feet.
No. 4.....	.55	3.30	8 84	12.72
No. 5.....	1.00	3.30	8.88	10.92
No. 6.....	2.40*	4.30	9.00	6.96

about 6½ volumes of air, and as the same coal is used to make London gas, they will serve to represent the results of burning London gas under the same circumstances. They show how much air may safely be mixed previous to combustion in a burner of a given size.

The burner used for this purpose had a tube seven-sixteenths of an inch inside diameter. The consumption of gas was maintained as nearly uniform as possible.

The tables indicate the changes in the appearance of the flames as the pre-admixture of air varied. The result showed that one and a half volumes of air was the maximum limit of preadmixture with a seven-sixteenth inch burner; if the air exceeded that amount, the flame would go down the tube and burn within. If, on the other hand, less than 65 per cent. of air were mixed previous to combustion, the flame began to burn imperfectly and deposit soot. There must always exist a certain proportion between the diameter of a burner tube, the quantity of gas passing through it, and the quantity of air mixed with the gas. A well-made burner will be equally efficient with gas at all pressures, from three-eighths of an inch up to any number of feet on a water column; and it is difficult to say how much gas may be burned through one tube. We have already observed that as the pre-admixture of air increases, the flame becomes smaller and more intense. Bearing in mind, then, that the nearer a substance to be heated is placed to the source of heat, the more rapidly the heat passes into it, we find that a vessel of water may be placed nearer the centre of the flame without interfering with combustion. There is also less risk of the flame being fouled in its own products when the amount of air it takes up while burning is reduced to a minimum.

In Table III. are the results of three trials made with the illuminating burner against the Bunsen burner. A vessel of tin-plate, containing one pint of water,

* Cone almost imperceptible, with short white tail.

was placed over an illuminating burner of the batswing form at a height above the flames chosen out of three trials at the best position. The same vessel and quantity of water were placed over the Bunsen burner with like precautions :

TABLE III.—*Gas burning at the rate of* 4.5 *cubic feet per hour.*

Experiments.	First.	Second.	Third.	Average.
	min. sec.	min. sec.	min. sec.	min. sec.
Batswing.....	12.43	12.45	12.48	12.45
Bunsen...	9.32	9.32	9.33	9.32

The results of this experiment serve to confirm what has just been stated. With gas burning in both cases at the rate of four and a-half cubic feet per hour, the water was boiled in 9 minutes 32 seconds by the Bunsen burner, whereas the batswing required 12 minutes 45 seconds. The balance in favor of the former is, therefore, 3 minutes 13 seconds, or 25 per cent. As the diameter of the Bunsen burner is increased it becomes more and more difficult to obtain a good and steady flame. Increase of length gives the air and gas more time to mix and produce a regular flame, but the slightest disturbance causes it to strike down. The experiment with the folded plate and the twisted wire as slight obstructions made a certain improvement, but could not be called a complete remedy. The rose top is the best known appliance, but when made of large size the combustion in the interior of the flame becomes imperfect, and, after all, it will not bear turning low without striking down. Another necessary condition also presents itself, increasing the difficulty of obtaining a good large flame. The proportion of air mixed previous to combustion must be greatly augmented because, the surface of the flame (which takes up the remainder of the air to render combustion complete) does not increase in the same ratio as the volume of the flame. If the flame be long and straggling, although giving off no unburnt products, it will certainly deposit soot when applied to the cold surface of a vessel of water ; it therefore becomes a matter of the greatest importance, that the burner be of a form that is free from the risk of striking back when lighted. To meet this difficulty the perforated cap has been devised, which by reversing the usual principle of construction, gives the most remarkable results. Instead of regulating the admission of air from below by partially closing the air orifices, it is done at the top by back pressure.

A cap of perforated metallic plate is fitted over the top of the burner tube and made to slide up and down, so as to adjust the number of openings through which the air and gas are to escape into the flame. The cap offers more or less impediment to the upward passage of the gas, and thus controls and regulates its power of drawing in air at the bottom. This burner has been found capable of burning every kind of coal gas with equal facility. When lit, and adjusted to the maximum amount of air, the cap is studded with brilliant green beads forming the base of the flame ; each bead corresponding with one of the perforations, while above you see a flame which is solid to the centre, and without that hollow inner space which has hitherto been considered a peculiar feature of all round flames.

A piece of fine wire put across the flame close to the cap is incandescent along the whole length enveloped in the flame coming from a burner two inches in diameter, and consuming forty feet of gas per hour. When I partially close the air openings, a hollow conical space immediately appears in the flame, and the wire cools to blackness. On again admitting the air the wire becomes immediately incandescent, and the flame is solid as before. In order to make the appearance of the beads more distinct, I shall use a cap, with much coarser perforations, which, if carefully lighted, makes a flame of marvellous beauty. The cap is now studded with an array of gems whose brilliancy would pale that

of the brightest emeralds. Their color is entirely on the surface, for they are hollow, and filled with the unburnt mixture of air and gas, and they fade and merge into each other on the slightest interruption of the air supply at the base of the tube.

These experiments all indicate that a great increase must have taken place in the amount of air mixed previous to combustion. This supposition has already been confirmed by measurement, proving that a burner two inches in diameter will burn safely a mixture containing 4.6 volumes of air per volume of gas.

Spectrum analysis has not yet thrown much light on the peculiarities of this flame. The carbon lines are exceedingly brilliant in the spectrum of the green beads, but the condition of combustion indicated is not clearly defined. It was at first thought possible that the increased temperature of the flame might cause a combination with the nitrogen of the atmosphere mixed with the gas, but a mixture of pure oxygen and coal gas gave the same spectrum as before, so that the nitrogen may be supposed to pass through it unaffected.

The application of coal gas to cooking seems to have had a fair amount of attention from competent men, and good and useful apparatus are easily obtainable; but it is otherwise with the gas stove, which shows scarcely any improvement for the past twenty years. It has been much ornamented, and that is all. The largest burner put in the smallest case that will hold it without becoming too hot seems to be the *ne plus ultra* of a gas stove. If a chimney is used, it is put at the hottest part of the stove case, so as to carry off the heat as well as the products of combustion, or still worse, the burner is put in a common fireplace, and at least seven-eighths of the heat go up the chimney. There is no more extravagant method of using gas than this.

Every one who has seen the coal stove in use on the Continent must be aware that its great heating power is due to a large radiating surface, and nothing else than a large radiating surface would give such a result. The same rule applies to the gas stove, which should be at least six feet high, and so arranged internally that the products of combustion should pass over the whole surface before escaping. The diagram shown represents a section of a gas stove six feet high and fifteen inches diameter, with a partition dividing it into two parts from the bottom to within six inches of the top. The products of combustion from the burner, pass up to the top of the division, and then down the other division, escaping on a level with the burner, after having traveled nearly twelve feet over a thin iron plate forming the radiating surface of the stove. The hot spent gases not only pass over a large heating surface, but they travel slowly, allowing the greatest time for the heat to pass through.

The speed of the draught (being regulated by the difference of temperature of the two columns) is always in proportion to the amount of gas being burnt, and the result is a balanced draught which never requires the control of a damper.

Let me show you by experiment the advantage of this arrangement.

A syphon of stove piping represents the stove case with its two divisions, and a small burner is placed below one end. The products of combustion pass up one half of the syphon and down the other, escaping at the level of the burner. To render this apparent I pass some smoke up from beside the burner, and you presently see it emerge at the outlet, showing that there is a continuous current through. The products of combustion are losing heat through the sides of the pipe as they travel along it, and the thermometers fixed half way along, and at the end, will give us an idea of the rate of radiation. The thermometer at the bend of the syphon stands at 220 degrees Fahrenheit, and that at the bottom or outlet indicates 95 degrees Fahrenheit, so the difference between these two temperatures represents what would be the loss from a gas stove, if the chimney were put at the top instead of at the bottom, and shows the absurdity of placing the outlet at the top.

The disposal of the products of combustion is the next matter for attention, for, although, they may be carefully turned into a chimney, they may be unable to ascend by reason of down draughts. This difficulty often occurs in heating conservatories having low

chimneys, and situated frequently in places where the force of the wind accumulates. There is the risk of extinguishing the gas which may afterwards escape, causing serious risk of explosion, and there is also the danger of having the products of combustion blown in among the plants, which would soon kill them.

The problem then is, how to prevent the down draught without closing the chimney, and thereby arresting the products.

The disturbing force of the wind down the chimney must be met by another equal force acting at the same time in an opposite direction. These two forces will meet and neutralize each other, and the products will continue to escape, as in calm weather.

I shall again have recourse to experiment, to show how this may be done.

Here is a box representing the stove case, which is placed below the syphon pipe. A flame burns in the box, which is air-tight with the exception of a small tube supplying air to the flame. The outlet of the syphon is extended so as to terminate close to the air supply tube. Both these tubes open in the same direction, and the orifices may be at any distance from the burner. We have now the outlet and inlet terminating so nearly together as to receive the force of the wind at the same time, and, although I make a violent current of air pass against these openings, you see through the glass window of the box that the flame suffers no material disturbance.

A gas heating stove cannot be said to be complete until it is fitted with an automatic regulator, which will only allow the gas to be burnt at such times and in such quantity as will insure the desired temperature.

I shall now show you an apparatus designed for this purpose, which owes its movement to the expansion and contraction of air confined in a closed vessel. Air is remarkable for the small amount of heat requisite to change its volume. An increase of one degree Fahr. will expand 491 cubic feet of air into 492 cubic feet; and, if it is not allowed to expand, by being confined, it will exert a pressure equal to a column of mercury one-sixteenth of an inch in height. A difference of a very few degrees, therefore, can easily accumulate sufficient force to close or open the gas orifice of a stove.

The second diagram is intended to show how this may be put into practice, and such a regulator will work on a difference of two degrees Fahr., lighting, adjusting, or extinguishing the burner as heat may be required, for weeks or months together.

The mode of action is as follows :—A thin copper cylinder of a certain capacity contains the air which is to regulate the gas by its expansion. This vessel is painted a dead black to render it the more susceptible to absorption or radiation of heat, and it has on it a small valve, the purpose of which will presently be described. A small pipe leads from the expansion chamber to one end of an invented syphon, containing mercury. The other end of the syphon has within it a tube suspended over the mercury, with its mouth at about one-eighth of an inch from the surface.

The gas to be burnt enters the cup at one side, and passes over the surface of the mercury into the central tube, up which it passes on its way to the burner in the direction of the arrows. In addition to this a tube takes a supply of gas to a small flame burning constantly beside the burner. As the air is confined in the vessel, the tube, and the cup, any increase of volume will depress the mercury in the cup, raise the level in the tube, and decrease the space below the central tube by which the gas escapes to the burner ; and if the air continues to expand, it will close it completely and cut off the gas. Then the surface of the mercury around the centre tube is acted on by the pressure of the gas while the surface within the tube is free, so the mercury within rises to a height proportionate to the pressure of the gas.

When the mercury begins to fall by reason of the cooling of the air in the expansion chamber, it still retains a higher level within the centre tube until its gravity overcomes the pressure of the gas, when it falls clear of the tube, allowing a free rush of gas to ignite the burner immediately by the aid of the constant flame. All that is necessary to set this regulator is to open the valve in the expansion chamber, and light the burner. When the desired temperature is obtained, the valve must be closed,

and a sample, as it were, of air at the desired temperature is shut up in the expansion chamber. Any alteration of temperature outside the chamber will affect the volume of the air within, causing a corresponding adjustment of the gas. If the gas were turned slowly on and off, there would be an escape each time it was lit and extinguished, but in this case the supply and cut off are sudden, while the adjustment is gradual.

With an apparatus of this kind a conservatory, for instance, may be heated with the greatest nicety. As sure as the thermometer falls below a given point, the gas will be turned on and lighted, and when the sun affords sufficient warmth, it will be extinguished until the temperature falls again.

That absence of sufficient heating surface, which has already been noticed in speaking of the ordinary gas stove, is equally remarkable in most of the hot water apparatus, where gas is the fuel used. Twenty-four inches is the maximum distance the heat is allowed to travel in contact with the boiler, and from eight to ten inches may be regarded as a fair average distance when speaking of the small apparatus of which the greatest number are sold. Is it any wonder that gas heating has been tried and condemned a hundred, nay, a thousand times; or that the public at large should be thoroughly satisfied that it has in it no element of true success.

I know of only one manufacturer whose hot-water apparatus shows any sign of thorough appreciation of the fuel he has to deal with. The apparatus is shown on diagram No. 3, which has been kindly lent by the inventor, Mr. Ezard, of Bradford, near Manchester.

The diagram represents a double range of hot-water pipes attached to a small boiler under which the burner is placed. Instead of carrying the chimney away from the top of the boiler, it is made to pass along the upper range of pipes, emerging at the return bend.

You will at once see how greatly the heating surface is increased, and this is not the only important advantage gained. The time of contact is extended in proportion, and the result is that the product of combustion escape at a temperature only slightly above that of the water. When we remember that water contains 3,234 times the quantity of heat which an equal bulk of air contains at the same sensible temperature, it will be evident that very little of the gas heat is going to waste.

No real progress can be made in the application of gas to heating until the following facts are fully recognized. No apparatus made to burn coal fuel is fit to be used for gas fuel, the condition necessary to insure good combustion being totally different. Gas fuel requires a large heating surface, and a very slow chimney draught, barely enough, in fact, to carry off the product; and this draught must not be disturbed.

Gas at 3s. 9d. per thousand feet costs 1½d. per lb., and yet it is now well known that cooking may be done with it not only better but more cheaply than with coal.

I shall now proceed to make a comparison between gas and coal as fuel for heating, and the figures will require very little to be added by way of comment.

Let us assume, as a basis, that coal costs the user 26s. per ton, and gas at 3s. 9d. per thousand feet in London, and on these data examine the cost of obtaining an equal amount of heat from the two substances.

In 1866, Dr. Letheby and Mr. F. J. Evans demonstrated that 1 lb. of coal completely burnt would produce the same amount of heat as 13 cubic feet of coal gas.

From the estimates of Dr. Neil Arnott, Mr. Edwards, author of "Our Domestic Fireplaces," and other authorities on this question of the heat utilized for heating a chamber by burning coal in a common open fireplace, it appears that on an average, one-eighth or 13 per cent. of the total heat of the coal is really available for the desired purpose. Eight pounds of coal would, therefore, be required to produce as much heat in a room as would be given off from a three-light chandelier burning 13 cubic feet of gas in one hour.

Their relative prices would be as follows:

	d.
8 lbs. of coal at 26s per ton.....	1.112
13 cubic feet of gas at 3s. 9d. per 1,000.	.585
Difference.....	527

In other words, the cost of the same

amount of heat in the two cases would be as 11d. to 6¼d., which is tantamount to saying that the coal heat costs 90 per cent. more than gas heat. As it is not wholesome to allow the products of combustion from a gas stove to escape into a room, a liberal sacrifice might be made to get rid of them by means of a chimney, without bringing up the cost of the gas to that of the coal.

There are certainly many methods of using coal which render it more economical than gas, but most of them are expensive to apply, and none possesses all the advantages of gas fuel. If the figures just quoted are to be relied on, gas is no longer to be regarded as a luxury for the wealthy alone. The poorest classes have generally the worst constructed fireplaces as regards heating power, and buying their coal in small quantities, they pay a higher price for it than do those who buy by the ton. It should be an inducement to the public to know that the use of gas in the daytime is more likely than anything else to reduce the price of it by giving uniform and complete employment for the apparatus at the gasworks, and it is neither impossible nor even improbable that at no very distant date coal or other gas may almost entirely supersede the fuel at present used in the dwellings of all our large towns.

There is one other application of gas heat to which it will on the present occasion be possible only to refer briefly. It is the raising of steam to drive small engines of not more than four horse-power. The demand for engines of this class is already very great, and a good substitute for the coal furnace is much needed, not only because it affects the insurance of a building, but also because a small fire requires much more vigilant attention than a larger one. There are already many gas-heated boilers in London and elsewhere, but they appear to be all constructed after the pattern of the coal-fired boiler, and the inevitable consequence must be a considerable waste of gas. The rules already detailed for the construction of heating apparatus apply equally to steam boilers. There must be the balanced draught, the large heating surface, and the greatest possible distance for the heat to travel before leaving the boiler. There must also be high steam pressure, and an automatic regulating valve on the gas-pipe, actuated by the boiler pressure, so as to turn the gas down as soon as the steam approaches the blowing-off point, and thus use fuel only as the rate power is required.

Such a boiler is already in the hands of a well-known firm of engineers, who intend to manufacture it in conjunction with small sizes of the already famous Willan three-cylinder engine. Results of the most satisfactory character have confirmed the experiments already made, and an exceedingly useful and compact apparatus may be expected.

There are various facts among the foregoing remarks which, if summarized, may lead to some useful conclusions regarding the constitution of the solid flame. Let us take the well-known Bunsen flame as a basis of comparison. There is the conical space within the flame, then a sheath or envelope of flame described by Faraday as the zone of partial combustion, and outside of all a second sheath or envelope, the zone of complete combustion. Although air has been mixed with the gas before it reached the flame, it is not sufficient to render the gas combustible. The mixture of air and gas ignites first around the edge of the tube, because there it meets the oxygen most readily, but the centre of the rising column of gas and air has to travel to the top of the hollow cone before it can meet the oxygen of the air, which rushes into, and combines with, the flame, with extraordinary rapidity. The thickness of the flame surrounding the hollow cone represents the distance the oxygen travels before it is combined with the gas, previous to escaping upwards as carbonic acid at a temperature which greatly increases its volume. Part of the oxygen is arrested in the outer sheath or zone of perfect combustion, and part presumably passes into the zone of partial combustion, producing a carbonic oxyde flame, which, as its material passes into the outer part, receives its complement of oxygen, and becomes carbonic acid.

It has already been observed that small flames require less air pre-admixed than large ones; this is due to the greater surface which they present to the air in proportion to their bulk. The

oxygen has consequently a less distance to travel into them.

In Table No. 1, a 7-16th of an inch burner would only bear 1½ volumes pre-admixed before becoming solid, whereas a 2 inch burner would require a mixture of 4.6 volumes to solidify it. If the small burner received more than 1½ volumes, the flame immediately descended and burned within the tube, its position in the tube depending on the excess of the pre-admixture. Before the flame descended, it exhibited the bright green film across its base, indicating the best state of combustion, and it retained the green film even when burning half way down the tube.

Now, when we remember that it requires nearly 6½ volumes of air to consume the gas completely, it is evident that the amount pre-admixed is not enough even to produce a carbonic oxyde flame, which requires just one half of the total amount. If, then, the combustion is complete, the flame must receive its complement of oxygen through the top of the tube, making its way through and against the current of products of combustion, whose velocity is increased by expansion into six or seven times their original volume.

Leaving the small flame, let us turn to the large one. The primary conditions are here very different. In the first place it has only one tenth part of the surface in proportion to its bulk that the small flame has; and in the second, the amount of air pre-admixed is 4.6 volumes, or about 40 per cent. more than that necessary to produce a carbonic oxyde flame. The flame is perfectly solid, from the green beads where it commences, up to the top. There is no apparent difference in the temperature of the flame from the centre to the outside, and the green beads (those most delicate indexes of any change in the proportion of oxygen in any part), are exactly the same in color and size at the centre as at the outer edge. The platina wire when suddenly placed across the flame heats apparently at the same rate in every part immersed, so there is much reason to suppose that this is a carbonic acid flame having neither the zone of no combustion nor that of partial combustion.

It must not be regarded as a group of separate flames, as the beads have no separate supplies of air; besides, a solid flame can be produced without the perforated cap, by making a sufficiently intimate mixture of the air and gas, as in the case of the smaller flame. Since the green beads are so uniform in size and color, we may reasonably conclude that they are burning under the same conditions, and one of these conditions is that the two and a quarter volumes of air necessary to combustion of the gas must pass to the very centre of the flame, giving every bead a uniform and equal supply.

It wold be interesting to learn whether the nitrogen of the two and a quarter volumes of air accompanies the oxygen into the flame, or whether it is partially or wholly dissociated before combining.

The subject has been treated throughout from the point of view of an engineer rather than that of a chemist, and more with a view to getting at the simplest and best modes of burning coal gas rather than of analyzing the phenomena of combustion.

The work of the chemist has been a good deal limited by the apparatus with which he has experimented; and it is with a hope that an improved form of burner may assist in the further analysis of a most important subject, that the matter has been brought before you.

THE sewage difficulty in the large towns in the United States is apparently becoming urgent. The drainage of a large city like New York cannot be poured with impunity even into an estuary almost filled with sea water, and the ebb and flow of the tide spreads the solid refuse that pours out of the sewers over a radius of nearly twenty miles. Looking forward to the probable increase of the city and the certain increase of the nuisance from sewage, it is now proposed to intercept the whole contents of the drains and carry them out to the sandy grounds of Navesink, where they will be filtered and made to produce, possibly, a good proportion of the animal consumption of vegetables. A company undertakes to do all this gratis, provided only that the privilege to make use of the sewage shall be given to it in perpetuity.

BRITISH IRON TRADE ASSOCIATION.

Inaugural Address of the President, Mr. G. T. CLARK.

Gentlemen: You have done me the honor of electing me as the President of our Association, and I am instructed that it is my duty, as it will be that of future Presidents, to commence their term of office by an Address.

He who finds himself in such a position naturally looks back to see what view his predecessors have taken of their duty, and, according to his taste or temperament, will either follow suit, or attempt to strike out something new. But I, unfortunately, preside over a new Association, and have, therefore, no indications what to avoid or what to follow. The channel I have to navigate is not as yet buoyed out. I have no skillful predecessor by whose wake I can steer safely through the narrows, nor are there as yet any wrecks on either hand to show where shoals or rocks may lie. Under such circumstances, I cannot afford to be ambitious, and therefore propose to confine myself to the humble but necessary duty of setting forth, as best I may, what, as it seems to me, should be the aims and objects of the Association. Our Association is composed of men who are largely concerned in and represent, what is not only one of the greatest branches of British industry, wielding an enormous capital, and giving employment, directly and indirectly, to hundreds of thousands of persons, but is also one which does not depend entirely or principally for its raw material upon foreign countries, and which, therefore, is less liable than some others to be affected by war or external disturbances, and is, besides, independent of climate or the uncertainty of the seasons. But although we do not necessarily exchange finished produce against raw material, it is not less the fact that we have extensive and intricate relations with foreign countries, and are called upon to take a keen and often a painful interest in their fiscal and customs' regulations. Moreover, the iron trade, including therein its subsidiary branch of the coal trade, is, beyond any other, exposed to the uncertainties which, in these days, attend upon the employment of labor, and has had, and it may be feared, is still destined to have, a larger experience than falls to the lot of other trades, of the modern difficulty, known as a "strike," which bears to the general prosperity of a trade very much the relation, whether for evil or for good, which is borne by war towards prosperity in general. For these reasons the Iron Trade Association claims to take a very forward place among the industrial representations of our country, and it will be for those, whom I have the honor to address, or who may afterwards become its members, by their contributions to its discussions or its transactions, to establish the position which it aspires to take up, and to do justice to the vast mechanical, industrial, and commercial interests, of which, with the Iron and Steel Institute, it is the representative.

Iron, if not the metal of highest price, has ever been that of the greatest value; that of which the world could least afford to be deprived; and it has played a more important part than any other mere material agent in the civilization of mankind. And if this be true of the earlier and the middle periods of the history of the world, it is still more remarkably so of the age in which we live, when the employment of iron in railways, in the fabric of ships, in bridge building, in floating docks, and for other purposes of construction, especially in large public buildings, has increased its production in a very marvelous manner, and has combined with other means, also of rapid growth, to alter all the conditions of the manufacture, and to produce a sudden and complete revolution in the trade. It is, moreover, observable that these changes excessive as they are, have not been brought about by war or violence, but by causes perfectly natural, though ordinarily slow in action, which during the last few years have operated with accelerated speed. Thus it has chanced that important trades, and considerable branches of manufacture, have sprung up or have decayed, or been directed into other channels, with very unusual, not

to say unheard of, rapidity, demanding on the part of those engaged in them no common foresight, no ordinary promptitude of action, so to meet the altering circumstances as to escape ruin, if not to extract out of them advantage.

There was a time, and that not long since, when the iron trade of Great Britain was in the hands either of individuals or of companies of a strictly private character, composed of a small number of partners. In those days the disposable capital was limited, and the attention of the iron master was confined pretty closely to the details of his manufacture, and to the sale of his metal at the nearest port. His channel of conveyance was the canal; his ore, flux, and fuel, were raised very near to his furnaces. He left his works, or at any rate his district, but seldom, and if his trade, over any length of time, was unprofitable, he had no resource but to wind up and retire. There was but very little legislative interference with his business. I have heard some of the fathers of the trade relate, with much satisfaction, the part they took when Mr. Pitt proposed to lay a tax upon pig iron: how they went to London, formed a committee, and saw and expostulated with the Minister. To some of the smaller of these men, the event of their business lives was this one bit of legislative agitation, which to many of us is almost an annual anxiety and annoyance. At that time, too, commercial treaties were unusual, and there were no combinations worth mention among the workpeople, making necessary counter-combinations on the part of the employer. The ironmaster of that time troubled himself very little about the relations between labor and capital, and in fact regarded his business from what would now be considered a very narrow point of view.

And yet the old ironmasters, who were produced by and who perfected this bygone system, were a remarkable race of men. They were men of whom England had reason to be proud. They were mostly self-made, strong, firm, not to say obstinate in their will, very self-reliant, rough but not unpopular with their workpeople, of great kindness of disposition, and they possessed that rare and great gift the power of managing men. Such were Sir John Guest, the Crawshays and the Hills, in Wales; the Knights and the Darbys in Staffordshire, and the Bairds in Scotland. A sort of natural selection weeded out the weak, so that only the strong survived. The very term "Ironmaster," long applied in no other trade, has a strong flavor of power.

Men, circumstances and conditions are now changed, and changed within our generation, within the business life-time of many of us. The joint-stock system, which has brought immense capitals into the iron trade, and in many instances been worked to the advantage of all, has too often found combinations of shareholders who, after losing heavily, year after year, by the trade, are still willing to go on, of course to the utter ruin of those who cannot afford to carry on their works without profit, and to the serious injury even of those who from more favorable circumstances or more skillful management are yet able to live. To take a slight liberty with some well-known words, I may say:

> "———— The time has been
> That when the cash was out the firm would die
> And there an end. But now, they rise again
> With loans and preference shares upon their brows,
> And push us from our stools."

It is not too much to say that in certain districts of Britain some millions sterling have been expended in the last ten or twelve years in producing iron which has been sold at a loss, utterly deranging the ordinary relations between demand and supply, and producing in the long run immense discontent among those very bodies of workmen whose wages have thus been artificially raised. In an old country such as ours, so densely peopled, so highly industrious, and therefore filled with trade rivalries and competitions, there must necessarily be, in every trade, occasional and serious fluctuations, but there exists no branch of British industry in which the fluctuations have been so frequent, the alternations between prosperity and depression so severe, as in our own. In the iron trade, great demand has led to excess of supply augmented by speculation, producing artificial prosperity, followed by depression and distress. Formerly the suffering followed quick upon and checked and corrected the error: now that those who supply the capital are not

usually they who manage the trade, the corrective is longer resisted, though its operation is finally more severe. This infusion of ill-managed and unproductive capital is one, and by no means the least, of the difficulties introduced of late years into our trade. The prosperity which was at its height in 1872, and which has been succeeded by the existing depression, exaggerated no doubt by hostile tariffs on the Continent and the exclusion of our iron from the United States, illustrates very forcibly the natural sequence which I have attempted to describe.

Although individual manufacturers have been prompt to accommodate themselves to these altered and altering circumstances, they have been slow to form combinations for united action for the common good, and for the acquisition of such general information concerning the progress of the trade as is the concern of all although it can scarcely be acquired singly. In fact, the manufacture has far outstripped what may be called the commercial and legislative divisions of the trade. We are somewhat behind hand in the collection and publication of its statistics, especially those of wrought iron and steel, and we are also far from precision in the returns of the value and character of our iron ores. So also with regard to the freight and general statistics of the conveyance by rail of iron and steel making materials. All inland, and, indeed, all ironwork, are more or less dependent upon railways for the conveyance of their finished iron, of much of their raw material, and often of their fuel, and information as to rates and speed of transit is very important, and should be known to the whole trade. So also with foreign tariffs and treaties with foreign States. The very existence of England as a power of the first-class, if not as an independent power at all, depends upon her being able to hold her own in the manufacturing world, and especially in the manufacturing of iron and steel. Her function for about a century has been to undersell other nations in the markets of the world. Her trade was created by the peculiar skill of her sons, combined with the moderate cheapness of their labor. This led to its expansion, attracting into it a larger capital, giving employment to greater numbers. The original cheapness rested partly on low wages, but the effect of augmented production was to create a larger and ever-growing demand for labor, to raise wages, to diminish the cost of living, and so to improve the condition of the laborer. Recently, however, this production, carried to extreme lengths, has been accompanied by a restriction in foreign markets; and now that nearly every Continental nation, and the United States of America, have decided to foster special native industries by artificial restrictions, it behoves those concerned in the British iron trade to keep a close watch upon commercial treaties and the tariffs of foreign States, to see that the former be acted upon, and the latter grappled with where not absolutely prohibitive.

So also with an equally important subject, Home legislation. Formerly, legislative interference was confined, or nearly so, to the raising of revenue by direct taxation, and there was much intermeddling, usually vexatious, and always mischievous, with the details of manufacture; checking, for example, the manufacture of glass, the making of bricks, the tanning of hides, limiting the admission of light and air into dwellings, indirectly prescribing the form of ships, and so on, supporting a considerable army of smugglers, met by a counter-army of revenue officers, and causing our ports and river mouths to be infested with tide waiters, and thus producing a present revenue at the cost of much crime, to the great discouragement of trade and commerce, and to the checking the operation of that great natural law, by which supply adapts itself to demand, and men are led to buy in the cheapest and sell in the dearest markets, and, in accordance with which, each nation should be left to supply freely that article which it produces at least cost. All this is now swept away, or nearly so, among ourselves. Under the teaching of Adam Smith, and led by Cobden and his disciples, England has discovered that, even in a fiscal point of view, light taxation upon the increased production caused by free trade, best fills the exchequer. Here, in England, at least, we no longer protect special trades at the expense of the general consumer, but rather have we reversed the process,

and, in many cases, we most certainly protect the interest of the many at the cost of the few. For the new system, though, on the whole, very advantageous to the development of trade and manufacture, has been accompanied by a change in the course of legislation that causes to the manufacturer deep anxiety, and demands his continual attention. Modern legislation interferes not so much with things as with persons and classes, and its tendency is in every case to add to the responsibilities and, in the first instance, at any rate, to diminish the profits of the manufacturer. Of legislative measures of this class, the Factory Acts, and the Acts limiting the hours of labor, are well known types, and each year brings into the committee rooms of the legislature a crop of bills almost always well intended, but not always wisely considered. The modern policy springs in the main from good motives, and, carried to a certain extent, has a direct tendency to raise the condition of the working classes, without crippling their means, or injuring the producing power of the country. All interference, however, with the details of a manufacture or the habits of the workpeople, or with the economy of labor, should be accompanied by a degree of knowledge that very few indeed not actually engaged in that manufacture can possess. Not unfrequently the bills brought before the committee contain provisions, which would either be impracticable to work, or, if carried out, would be even more injurious to the class they are intended to protect than to the employer. All legislation of this nature requires to be jealously watched; where sound, promoted; where unsound, vigorously opposed.

Such are the general considerations which have led to the formation of our Association, of which the objects are briefly and conveniently described in the words of our prospectus.

"To secure a means of communication between members of the Iron and Steel trades of Great Britain, upon all matters bearing upon the commercial interests of these industries.

"To procure and circulate detailed statistics of the Iron and Steel trades, both at home and abroad.

"To attend to all matters connected with foreign tariffs, commercial treaties, and Home Parliamentary business, that may have a bearing upon the position of the Iron and Steel trades—excluding questions of wages, or of a purely local character—and generally to take all proper measures for advancing the interests of the British Iron and Steel trades in all their branches."

It is evident that the best way to carry out these aims is by means of an Association. The illustration of the bundle of sticks is as applicable now as it was in the days of Æsop, besides which Associations are not only stronger than individuals, but if well managed they grow stronger as well as wiser as they grow older. This is an age of associations, but although there already exist several, such as the "Federation of Employers," the "United Chambers of Commerce," and the "Mining Association," of a general character, there has no one hitherto been formed specifically to promote the iron trade in its commercial and legislative aspects. With the local iron trade associations, of which there are many, and those excellent, we do not interfere. Such bodies deal with local questions, in which the regulation of wages, and of railway and canal arrangements, form the most important features, and are best left to be so treated. Where these societies touch upon larger, and what may be called imperial questions, we can afford them valuable assistance, since we aspire to promote the interests of the whole trade, and to become on certain classes of subjects, its representative.

But, it has been asked, though it be necssary for the interests at stake that they should be made the care of a specific association, could not this end have been more conveniently attained by a committee or subordinate branch of the Iron and Steel Institute, already so powerful and so successful? The answer to this suggestion is that the Iron and Steel Institute owes its strength and brilliant condition mainly to the fact that it is busied exclusively with the manufacture, and does not meddle with the trade. It is with technical points only that it is concerned, and it is upon inventions and improvements in the manufacture that it undertakes to disseminate knowledge. Its ordinary meetings afford opportunities for discussions of this character, and it

annually visits one of the great industrial districts of the country, and its members become personally acquainted with such establishments as are best worth attention. Its leading members are all men who, though necessarily more or less conversant with the trade, are mainly celebrated for their knowledge of the details of their manufacture, and for the improvements which many of them, as, for example, Bessemer, Bell, Siemens, and Menelaus, have introduced into it. It is the powerful impulse given by the Iron and Steel Institute which has forced upon us the knowledge that it is not upon the manufacture alone that the success of our business is dependent. The more perfect our processes, the greater our economy of production, the more keenly are we made to feel that our business has another and not less important side, a political and commercial no less than a material economy; and it is by following the example of the Iron and Steel Institute and confining our attention strictly to our own classes of subjects that we can alone hope to rival that body in its success. It may also be remarked that, although the leading ironmasters are concerned necessarily with both branches of their business, and would be as much at home here as in the meetings of the Institute, there are many persons engaged in the trade whose experience and position give great weight to their opinions, but who, taking no part in the manufacture, and excluded therefore to some extent from the discussions of the Institute, will find an appropriate and very useful sphere of action with us. For these reasons, it has been decided to commit the commercial and legislative interests of the trade to an independent society, and it should be the care of those who are members of both bodies to promote that unity of action and cordial concord between them which it is for the interest of the whole trade should be preserved.

And, first, as to the statistics of the trade. "Nothing," said a witty statesman, "is so fallacious as figures except facts," and yet it is to facts and figures that we must look for that precise and trustworthy knowledge of the current condition of the iron trade in our own and other countries, which is so needed by each of us for the proper conduct of his business. It is important to know as accurately and as quickly as possible what is doing, or has recently been done, in production or in sale. An accurate and early account of the quantity of iron produced, of its various qualities and forms, with information as to the variation in the stocks held, will enable the manufacturer to form a tolerably correct judgment as to the relation between supply and demand in the trade as a whole, and in its various branches. We want to know, what is the production of each kind of iron in each district, what is the demand for it, whither it goes, how it travels, what it fetches, and, if possible what was its cost of production. And so of steel: it is important that we should know at what rate rails of steel are taking the place of rails of iron; whether steel is displacing iron for other and what purposes, and to what extent; and whether iron rails of a high class are superseding those of a lower class. These are questions very interesting to the manufacturer, but many of which at present can only be answered inaccurately by estimate, if not by guess. With precise knowledge on these and similar points of manufacture and consumption, at home and abroad, coupled with attention to the growth of railways and other large iron consuming works, the ironmaster will be far better able to decide, than at present, whether he should restrict or augment his output, and in what direction the necessary alterations should be made.

So also of the materials employed in iron making. We should have information from our own and if possible from all iron making countries, whence and in what quantities, of what quality, and at what price, are derived the ores employed. These, and the like statistics, collected, some by foreign governments, some by our own, and some by private associations, some given voluntarily, some by compulsion, and some not, as yet, given at all, we propose to collect and collate, and as far as possible to supply what is deficient. At this time it is impossible to deny that that immense division of British industry, known as the iron rail trade, is slipping out of our hands. From some reason or reasons, the iron rail trade, recently so large, has shrunk to nothing. It is true that no

amount of statistics would have prevented this, but I think that we ought to have had, and might have had, the means to foresee and provide for this change earlier, and far more effectively than we have done.

The branch of science known as statistics, is of modern growth, and is in some degree the business of the state, that is to say, those particulars which can only be obtained by the government, it is the business of the government to collect and make public. Such are the population returns of a country, its vital statistics, the particulars of its finance, its pauperism, its crime, its public burthens, its shipping, its trade and commerce, and in some degree of its agricultural and manufacturing industries. These are matters on which statesmen, those who legislate for a country, need to be informed. Their collection was long neglected by all governments, and has only of late years received much attention from our own. The well-known Northampton tables show in a very striking way the mischief of this neglect. They were collected in the latter part of the last century by private persons, and being, on that accouut, drawn from a limited number of observations, gave an erroneous average of the duration of human life, so that for many years the rate of assurance was unnecessarily high, and the enjoyment of this, the most beneficent gift of statistics to mankind, and one of which England is the parent, was seriously retarded. Since 1834 statistics have been under the protection of a very valuable Society, and we have from the Government minute and accurate returns of trade and commerce, of the circulation, crime, pauperism, and more recently of the mining and metallic operations in the whole kingdom. As regards our own manufacture, its statistics are placed under the Geological Survey Department of the Government, and, as this is a subject that concerns us deeply, I must ask your attention while I enter upon it at some length.

In 1838 the Council of the British Association for the advancement of science passed a resolution strongly urging upon the Government the collection and preservation of the mining records of the kingdom. The result was that in 1840 the "Mining Record Office" was established and a Keeper appointed. It was not, however, until 1845 that the present Keeper succeeded to the office, and his first care was to collect and publish mineral returns. These returns were purely voluntary, and as the Government made no specific provision for their publication they saw the light in an indirect form, first in the memories of the Geological Survey, and afterwards in the records of the School of Mines. These returns, however, were confined to copper, tin, lead, and silver, and did not include iron or coal.

In 1853 the subject was again pressed upon the Government, and since that time the mineral statistics of the kingdom have formed an annual volume that has gradually become more and more complete, and now forms a most creditable and valuable collection. As regards the metalliferous mines, since 1848 these returns have been voluntary. In 1854, the Inspectors of coal mines were directed to give assistance to the Keeper of the Records, and he was allowed traveling expenses, so that he might exercise more influence upon the coal proprietors, whose returns, to his department, were still to be voluntary.

In 1873, the Coal and Metalliferous Mines Acts, 1872, came into operation, and the returns from mines and collieries were made compulsory, but so little was the mining record office regarded that the Acts excluded the Keeper from a right to the use of the Inspector's returns. At this time the metalliferous mines returns are sent to the Keeper by the courtesy of the Home Secretary, but these give the quantity only of the ore raised, and he has still to apply to the proprietors for their money value, without which the returns would be far less useful. The proprietors, who have throughout shown much courtesy, naturally complain of having to make double returns where a single set ought to be sufficient; but having attended to Mr. Hunt's requests for 28 years, they do not refuse compliance, though certainly they ought to be relieved.

The returns now published by the Keeper in his annual volume, show, as regard iron: the blast furnaces built in the year, blast furnaces in blast, annual make of pig iron in each district, and the coal consumed for all purposes in its

production. As to wrought iron, they show the number of mills and forges, the coal consumed in them for all purposes, the number and capacity of the Bessemer converters, and the particulars of about half the tin-plate works. They show also, in raw material, the particulars of ore raised in each mine and in each county, its general description, its quantity, and its value: also the burnt ore from pyrites and other foreign ores imported, together with large, though not complete, particulars as to ore conveyed by coasting, vessels, by canal, and by rail.

In France, Belgium, and Prussia, the returns are compulsory, and are made to and published by the Government. They are of the same general character with our own, in some respects more, in others less, complete.

Now, although our returns are not by any means perfect, they are very valuable, and it is a creditable fact that they are all given voluntarily, and Mr. Hunt, who may be said to have created the department as it now exists, and by whom the annual volumes have been compiled from their commencement, does not wish it to be otherwise. He is of opinion that, with proper arrangements, all that is obtained by foreign governments by compulsion, might be obtained here, quite as fully and correctly, by free will. But for such work the present establishment is insufficient. I have taken the pains to inquire into its particulars, and I find that for a Keeper and two assistants, traveling expenses, and expenses of collecting records, the Government allows less than the salary of a senior colliery inspector. With the practice of the department in seeking information, most of us are familiar. It is simple. Circulars are addressed to the several manufacturers, with schedules which they are invited to fill up. Most do so at once. To those who neglect to supply the information sought, the Keeper makes a personal application. It is seldom that he has to take this step, and very rarely indeed that he takes it in vain.

This subject of the Mining Record Office is one that the Iron Trade Association should at once take up, nor could they well find a stronger case. There are certainly no statistics published by the Government that more affect any of the great industrial interests, none which, so far as they go, are more useful, none which require so little addition to render them complete. I think, too, that it may be said that no department is more economically worked, or, with the narrow means at its disposal, has produced more valuable results. The defects in the returns are the fault of the Government, or rather of successive Governments, with whom statistics have never been popular, and who have not as yet afforded the necessary staff for their collection, and, what is of equal importance, for their rapid arrangement and publication. I may also remark with much satisfaction that by a happy coincidence the same statesman who, in 1853, was at the Treasury, and whose report then made caused the Mining Office to be placed on an improved footing, I mean Sir Stafford Northcote, is now Chancellor of the Exchequer, and may fairly be expected to regard with favor the past success and proposed completion of his work. It may be thought I have dealt too strongly and at too great length upon the importance of statistical details to the individual masters, but in truth it would be difficult to over-rate their value. We want them complete and we want them early, and if the Association does its duty we shall soon obtain them.

I have pointed out briefly what is done in this matter by the governments of the Continent, but we have more to learn therein from the United States, where, as here, the reports are voluntary. The American Iron and Steel Association, in some form or other, has existed twenty years. The current report for 1874 was published in February 1875, and that for 1875 is probably now on its way to England. These reports, though of moderate size, are far beyond anything of the kind published in this country. The volume for 1874, for example, gives an account of the iron trade of the world, showing its fluctuations and their direction, their extent, and the range of its quantities and prices. The report further shows how far such fluctuations are affected by the laws of each country, where legislation is thought to be unwise, and how it should be corrected. There are tables of foreign commerce and of domestic production of the various kinds of iron showing the quantities produced in each of the twenty-five iron-

making States, of pig, of rails, whether iron or steel, and their prices, with the mileage of new railways. Also, a sketch is given of the iron shipbuilding trade; of great works, as bridges, in iron; of the rising make of Bessemer steel and that by other processes; of the production of rolled iron generally, and of the supply of iron ore. Besides these and other domestic topics, the report contains an excellent paper on the relations of capital and labor in the States. The domestic statistics form an appendage to the general report. We may indeed lament that throughout these volumes a narrow and exclusive system of protection is advocated, but we shall do wisely to take example from the energy and general intelligence displayed by the American Association, and shall do well if we are able to rival them in the value and completeness of the information which we may from time to time bring forward. It should also be borne in mind that the American statistics are not only, like our own, given voluntarily, but are collected by the Association, not by the Government.

France also contains a representative iron association, the transactions of which appear periodically as the *Bulletin du Comitê des Forges*, a very valuable publication, very full of facts and statistics of the French trade, both internal and with other countries, and in some respects, more full than the returns from England or the States. There are also associations of a like character in Belgium, Prussia proper, Westphalia, and the Rhenish Provinces, in full activity and of various degrees of merit, the proceedings of which deserve to be better known in England, and will, no doubt, become so by means of this Association.

But, however copious and accurate may be the statistics we may obtain and circulate, the mere collection and publication is but a part of what is wanted. These figures are the raw material which it would be our business to smelt and refine. We must use them as means to an end, and upon the manner in which they are handled and the soundness of the conclusions drawn from them, will depend, in a large measure, the usefulness and character of our body.

Next have to be considered the commercial and legislative conditions of the iron trade, two points very closely connected, not, indeed, naturally, but because questions of commercial treaties and foreign tariffs, as well as of home legislation are usually approached through the Government and through Parliament.

The general policy of the leading countries of Europe and of the United States leans strongly towards protection, and the effect, in the iron trade, has been in a great measure to shut out British iron from France, Belgium, Germany, and the States, and Russia seems following in the same track. In each country, specific interests outweigh the general good, and the profits of each trade are enhanced at the expense of the public. No combination of Englishmen can at once work a change. England could indeed exclude, as formerly, French wines and manufactures, and Russian hemp and tallow, but to do this would be to commit the very error of which we complain, to punish our masses for the advantage of certain specific trades, and to depart from that practice of free trade which Adam Smith regarded as too Eutopian a blessing ever to be enjoyed among men, and of which England stands nearly alone as the apostle. But if we cannot at once lead foreign nations to follow our example, and can only trust to time and the diffusion of knowledge to bring about the change, still we need not altogether despair. In our own country it was only by the steady exertions of a small but active minority that the change was brought about, and both in France and the States exists a strong and probably an increasing party in favor of free trade, in conjunction with which we may do something to enforce the observance of existing treaties, and watch over their renewal. Something may also be gained by the obtaining accurate information as to what form of iron can be exported at a gain, so as in some degree to turn the flank of a hostile tariff if we cannot meet it in front. And so as regards the importation of raw material from the Continent. You are aware that at this time English capital has been largely invested in Spain in opening iron mines and in forming communications with the port of Bilbao, and that the Spanish Government, if Government it can be called, has taken occasion, when

that quarter of the country is convulsed by insurrection, to lay an export duty on a trade which they ought, for their own sake, to encourage by every means in their power. To this impost our Association should have something to say, both before our foreign minister and at Madrid.

In home legislation we may hope to effect much more. Each year brings before the Committees of Parliament, bills bearing directly or indirectly on the iron trade, and often pushed forward by the trades' unions and by the force of public opinion, which, when ignorant of the circumstances, is commonly against the manufacturer. Our Association, strong in its representation of a great and wealthy trade, and in the accurate knowledge concerning that trade possessed by our leading members, should sit in council upon each projected measure, weigh well its provisions, and, while accepting in good faith those social improvements which are the object of what has been called Factory Legislation, take care that these be effected with as little interference as possible with the details of the manufacture and the habits of the workpeople. If we are guided by a desire, not to secure temporary profits, but to advocate what may be best for employer and employed, whose interests, often, temporarily or apparently, at variance, are yet in the main identical, we shall win the respect of the working classes and the confidence of the trade, be listened to by the Legislature, and be in a fair way to fulfill the hopes of the founders of our society.

There is yet another branch of public business, allied to the former, which comes within our scope. It will be for us not only to endeavor to influence our law makers, but to have something to say to the administration of the laws regarding our trade when made. Formerly, when a law was passed, it was in most cases left to be called into action by those whom it concerned, and an informer was stimulated to bring it into operation by the prospect of a share in the penalty inflicted, if a fine. The modern system is different. Many of the laws passed on behalf of the working classes are obnoxious to, or at best disregarded by, those whom they are intended to benefit, and to secure the application of such laws, the Secretaries of State and the Committees of the Privy Council and other Government departments are invested with almost despotic power, put in action through a cloud of inspectors amenable only to the central authority. Our schools, poorhouses, cottages, workshops, collieries, engine houses, are all under inspection. Hours of work, public clocks, sewers, water supply, rubbish heaps, water-courses, are all visited by men who exercise inquisitorial functions, and who, though usually chosen with care and some regard for their fitness, are, at the least in the earlier part of their career, more distinguished for zeal than for experience. This system, probably on the whole good, and to some extent absolutely necessary, is very liable to abuse, and needs to be very carefully watched, so that what is objectionable may be removed or amended.

There is a close and an increasing connection between the iron trade and the railways of the country, not only as regards the manufacture of the rails, but as regards the conveyance upon them of ore, fuel, and iron. To the introduction of railways is due the great development of the iron trade, and it is the continued demand for railway iron that has raised and maintained this trade as one of the great industries of the world. Where other customers have taken from us scores and hundreds of tons, railways have taken tens of thousands, and to them it is mainly due that, in the thirty years following their introduction, our make of malleable iron quintupled. Nor is it only as customers that railways have benefited our trade. By the facilities they afford we are enabled to draw our ironmaking materials from sources that would otherwise have been closed. Forty or even thirty years ago, the convenient conjunction of iron ore, coal, and limestone, was the cause of the prosperity of some of the most important seats of the manufacture. This is no longer the case to anything like the same extent. By the rail we can transport the coke of Durham at a cheap rate to the Cleveland iron stone, and the same admirable fuel across England to the rich hematites of Barrow. It is not too much to say that, but for the facilities of transit afforded by railways, the progress of Middlesbrough must have been

slow, and Barrow could scarcely have existed at all as a great centre of the manufacture of iron and steel.

But, much as we owe to railways and the railway system, and good customers as we and our brothers of the coal trade are to them, our interests are by no means identical at all points, though our alliance need not be the less cordial that it requires careful and constant watching. Railway managers are a very able and a very quick-witted class of men, and though generally aware, and ready to admit in the abstract, that the safest profits are those derived from low rates and great facilities for transport, they sometimes are found to sacrifice these broad and well-formed views for present gain. It is true that the ultimate object of a railway manager is the giving a good dividend to his share-holders, and not the development of the resources of a district, but what we have to keep steadily and powerfully before these gentlemen is the fact that these two points are in the main inseparable, and that, not only where the resources of a district are large, but even where they are but moderate, it is sound policy, even at a present loss, or with a very moderate margin of profit, to induce their development. Sam Slick's plan with his clocks was a very good one. Lend your clocks freely and after a short time people find they can't do without them and will purchase. Once let a railway be at work and the interests which it generates become too strong to be allowed to drop. Many of us know cases in which a single railway has held the monopoly of a district and checked its progress, as proved by the vast increase of trade which has followed upon the opening of rival lines.

This subject of facilities of transit is one to which the attention of our association should be directed, and the just and wise regulation of which we should promote with such influence as we may possess. As the margin of our profit becomes less, so much the more important does it become, that we should have cheap and convenient facilities for the transit of our raw material and our finished or half finished produce, nor are there any two points in England so distant that a profitable trade might not be made to spring up between them by a liberal railway policy, or, what is even more important, the trade between which might not be diverted or even destroyed by one of a short-sighted character. When I state that in stirring times the pig iron of Middlesbrough is actually brought by rail to South Wales, I adduce a very strong argument in favor of cheap transit, and show how extreme a case is made possible under a liberal railway policy. To obtain and maintain the exercise of such a policy, no exertions on our part should be wanting.

We have proposed, and I think wisely, to exclude from the scope of our association "questions affecting the regulation of wages or those of a local character." These are best left to the consideration of the associations now to be found in every manufacturing district. For their equitable adjustment they require a close knowledge of circumstances, and are besides accompanied too often by irritations and heartburnings and mutual animosities, which it is very undesirable to import into our discussions. But it by no means follows that the philosophy of wages, and the distribution of returns between labor and capital are not to be considered here, as well as those questions of interference with natural laws and individual freedom of action which are connected with fluctuations in the price of labor, and with the general relations between the employer and employed. For such questions lie at the root of our own and every other trade. Upon their solution rests the prosperity, not only of our trade or of our country, but of the whole world; and the statistics of production, commercial treaties and tariffs, and home legislation, important as such subjects are, sink almost into insignificance before that one great question of the wages of labor.

Labor and capital, which is the accumulation of labor, are co-equal powers. Without labor, capital yields no return, and will be dissipated: without capital, labor cannot be employed to advantage, and the laborer cannot rise to independence. Unfortunately, this truth, which is as fixed and indestructible as any other of the laws by which the world is governed, has not yet forced its way into the understandings of the masses in this or any other country. If it be too much to say that labor in England, as in the

centres of manufacture in France, has declared war against capital, it is at least that it places itself in opposition to capital, and the employer, who but recently was regarded as a useful citizen, is now, to some extent, thought to be one who desires to reap where he has not sown, or at the best claims more of the joint produce than he ought to do. The causes of this change are deep-seated. During the last half century, since the end of the wars of the first Napoleon, there has arisen all over Europe and in the United States a great development of the industrial arts, fostered by the general use of steam power, by vast improvements in machinery, by the tendency of such machinery to create large establishments and augment already over grown towns, by the construction of railways and steamboats, by immense facilities in postal communications, by the removal of the tax on newspapers, and, finally, by the invention of the electric telegraph. The effect of all this has been a rise in the wages of labor, not nominal only, such as might be produced by the greater plenty of the precious metals, but real—great and rapid beyond anything before experienced, and raising, in every article into the production of which labor at all largely enters, the cost of production in a far higher proportion than that of the necessaries of life, though most of these have also risen, and considerably. During that long period from the commencement of the reign of Louis XIV. to the battle of Waterloo, while other nations were distracted from the arts of peace by war or the apprehension of war, England, from her insular position, was at rest, and became gradually a hive of successful industry. During the latter part of that time she was supreme in the markets of the world for manufactured goods. The English capitalist took the lead in boldness of adventure; the English artisan in skill and perseverance. "Indocilis pauperiem pati," the device of the merchant venturers of one of our great seaports, was the sentiment of the whole nation. In the employment of her coal, the construction of her machinery, the outlay of her capital, the industry of her artisans, and the force and energy of her marine, England had no co-rival. "Wherever," said Napoleon, with the bitterness of deadly hate and envy, "wherever a cockboat can float, there I find the British flag," and beneath that flag were poured forth the cotton and the cutlery of Britain.

But the fall of Napoleon, and the repose that followed, enabled other nations to come forward in the race, and whatever may have been the continued progress of England, and it was great, France, Belgium, Germany, and the United States, gained greatly upon her, though even as lately as the introduction of railways on the Continent, Mr. Brassey could testify that, although English wages were higher than in any other country, railway works could be executed more cheaply by English than by any other labor.

There arose in England a belief, and a not ill-founded belief, on the part of the artisan, that he obtained too small a share of the returns to which, by his industry, he had largely contributed, and for this larger share, as for all good things in this world, he had to contend. At first, in the ignorance in which the working classes had culpably been suffered to remain, they had recourse to riots and open violence, but by degrees, better instructed, they formed the combinations known as trades unions, organized at first as provident or benefit societies for the sick or aged, afterwards extended to take in hand the regulation of wages and particulars of labor, and, from time to time, with perhaps equal excuse, but with less wisdom, employed also in political questions.

Our immediate and direct business as British manufacturers, is with British unions; but as these combinations exist in extreme forms elsewhere, our Association will have also to pay attention to the fruits which they produce in other countries.

Now combinations on the part of the artisan classes and in their interest are natural and right, and, since the alteration of the law in 1824, are legal. Although capital and labor are so intimately connected that one cannot be deeply injured without injury to the other, they have also points of variance, and it is only by a conflict of forces that a resultant course, representing each, can be arrived at. What has to be secured in these struggles, in the interests of the

whole community, is that neither party interfere with that entire freedoom to employ himself at pleasure in any lawful trade, which is the ancient right of every man under the common law of England, and which, though from time to time hampered by statute, was never lost, and is now once more fully recognized by the legislature. Trades' unions being thus in themselves lawful and right, and the recognized organs of labor, it becomes essential that their course of action should be understood, and this must be gathered not so much from their professions, though these are not indistinct, as from their practice. Their first and main, and very legitimate object, is to increase the wages of labor, and to bring this about by the means, equally legitimate, of combination. But having, by the setting forth so desirable an object, by means so legitimate, obtained the confidence of the artisan classes, they proceed to steps of a different character. To raise wages they adopt means which diminish production, and this by restricting the number of artisans admitted as apprentices into a trade, by shortening the hours of work, by discouraging piece work, and, where possible, the employment of machinery, and it is difficult to say which of these devices is the more opposed to sound principles or to the general interests of the whole commonwealth.

What rent is to land and wages are to labor, profits are to capital, and as they form the residue of the fund of returns out of which, where a trade is successful, wages must ultimately be paid; anything that diminishes that fund has, so far, a tendency to lower wages, and, therefore, whatever means are adopted to obtain for the laborer a larger proportion out of the fund, great care should be taken that they are not such as to diminish its total amount. But profits depend for their rate upon the cost, not upon the wages, of labor, and the cost of labor is determined by the proportion between the wages of the laborer and tha value of his production; consequently, measures that have a direct tendency to diminish the quantity of an article produced and to raise its cost, will, so far, depress the trade in favor of rivals who are allowed more freedom of action, and so will work injury to all. To restrict by artificial means the number who may follow any particular trade is only to throw upon the mass a number of persons who might be better employed, and who, by adding to the general supply, have a direct tendency, to lower the average of wages.

Profit, or that which remains to the employer when his capital is replaced and the wages of labor have been paid, is the joint produce of capital, skill, and industry, but it is an error to represent it, as is now often done, as the fruit of industry alone, and therefore the property of the workman; nor is the step from this a great one to that of representing the interest of the employer as altogether opposed to those of the employed, and seeking to compel him to raise wages with but little regard to the source whence alone they can be derived.

As to the hours of labor, it may be admitted that in some trades they have been too long for the average workman, and so far as they tend to depress him physically and intellectually were therefore injurious to the community. Relief on this head was no doubt needed, but to forbid any man, whatever may be his strength or skill, to employ those qualities for his special benefit was scarcely the way to bring it about. The tendency of such an order is to place the weak and strong, the skillful and the unskillful, the idle and industrious, on the same dead level. It is true that in practice the Unions do not carry their opposition to piece-work to the length of absolutely prohibiting it, but the arguments employed by them, if followed to their legitimate consequences, would be prohibitory The manner in which these restrictions have been enforced, is equally objectionable with the restrictions themselves, and includes all methods of coercion from social exclusion up to serious bodily injury and even death. All individual liberty is forbidden. The conditions of labor are dictated by a committee of delegates whose deliberations are, not unfrequently, kept secret, and whose authority is paramount.

It may be said, probably with truth, that the regulations of the Manchester and Sheffield Unions, conceived in ignorance and enforced by crime, are confined to unions composed of the lowest and most ignorant class of workmen, and are disapproved of by all others. Still,

admitting this to the full, the violation of sound economy and the interference with individual liberty are rather in degree than in principle.

Of course it often happens that a Union is not strong enough to carry out its wishes to their full extent, but their tendency is such as I describe. Even if the restrictions were in themselves in some respects beneficial, they are not the less an interference with that individual freedom for which we in England have struggled so long; and their direct effect is to lower the standard of excellence attained by British industry, to deteriorate quality, to check quantity, and to enhance cost, and to do this by forbidding individual freedom of action, and diverting the natural course of labor into artificial channels. It is scarcely for a Government, still less for an irresponsible and private body, to judge what trades are overcrowded. That this and similar points are best left to be settled by natural laws is a truth which we in this country have been slow to learn, but which we have learned, and will, I trust, yet maintain.

Moreover, this system of interference with natural law, supported by petty annoyances, rising to social terrorism, is even now producing its effects in England by the stimulus it affords to the productions of other countries. Belgium already runs England very close in all her great industries. Wages in that country are far lower than here, and the cost of living is about the same.

Her artisans are skillful and industrious, and her progress has been effected during a period when her very existence as an independent nation was threatened.

There is the less excuse for this suicidal policy that not only in Belgium but in France and Germany, wages are lower and the position of the artisan less advantageous than with us. Here there exist few or none of those old legal restrictions on trade that linger in parts of the Continent, and especially in Germany, and which are described as having been, in the United States, at at the close of the late war, far more vexatious than those prevailing in England in the days of Mr. Pitt, and the contemplation of which drove Mr. Wells to become a freetrader. In England, food, clothing and lodging, are as cheap or cheaper than on the Continent, and the industrious, prudent and skilled workman can at this time do better for himself here than even in the United States. The Consular returns to the Foreign Office, first called for by Lord Clarendon in 1869, returns which might be consulted with advantage by our working classes, show that in no country, excepting perhaps Holland and Switzerland, is an artisan better off than in England, and in Switzerland the difference seems to be due only to their greater frugality and the absence of intemperance.

In these disputes about labor, as in not a few of our national troubles, the cause is mainly ignorance. The English artisan is not usually by any means a vicious man. Even where he joins in attacking employers as a class he not unfrequently bears no sort of malice against his own employer. He does not seek to regenerate his country by bringing every capitalist to the scaffold, or even to the poorhouse, or by destroying public monuments or other evidences of national greatness or accumulated wealth. Where the individual master, and, in some considerable degree, where the masters of a special district are allowed to deal directly with his or their own men, the men are usually willing to listen patiently to reason. Nevertheless, it is vain to disguise or deny the fact that British workmen by their representatives the trades' unions, are at this time acting in opposition to the doctrines of free trade and of freedom of action.

The drift of the Western world, ever since the invention of printing, has been all in one direction, and every movement has contributed to improve the condition of the mssses. Privilege after privilege, restriction after restriction, has crumbled away. The discovery of America, the doubling of the Cape of Good Hope, the use of gunpowder, the reformation in religion, the colonization of the fifth division of the globe, every discovery, every invention, has been a step in the same direction, tending powerfully to equalize social conditions, to break down divisions, to bring about, not that equality of individuals which is the empty but dangerous dream of the socialist, but the removal of artificial restrictions,

and to allow each man freedom to employ his powers in that way which seems to him the best, and which has been found to be on the whole the best for the community.

But a few years ago, the policy of protection was almost an integral part of our industrial system, in manufactures, commerce and agriculture. And yet in England, a country very distrustful of change, as change the voice of reason has been heard, and great and powerful interests, such as those involved in the navigation laws, and the growth of corn, have given way. It has only been after severe struggles, and at great cost to many specific interests, that perfect freedom of manufacture and of trade, and individual freedom of action, have been won and established, and we are now asked in the interests of labor to reverse this decision, and to return to a system of restrictions and interferences, which is at direct variance with all our convictions.

I have touched at some length upon these burning topics, I hope in no spirit of cavil or exaggeration. I have described the operation of Trades Unions, as they are now, or have recently been, carried on, and especially as they affect the iron, and its subsidiary, the coal trade, and this I have done because, although it is highly undesirable that this Association should become an arena of controversy, it cannot but be that we shall have to give our attention, and our most serious and anxious attention too, to one of the most complex and most pressing problems of modern times, and one upon the solution of which depends the prosperity of our own trade, and, in a great measure, that of our own country.

Our Association enters upon its existence in a time of general depression, and one in which we have to grapple with new and somewhat formidable dangers. But the qualities which have gained will maintain success, and they know but little of England, who suppose that the energy and boldness of our capitalists, or the skill and industry of our working classes have seriously fallen of, or that our internal disputes will not be conducted, on the whole, with that practical sense and moderation to which we, as a nation, lay claim. Even now, dark as is the hour, and deep the winter of our discontent, there are not wanting symptoms of a revival, nor, perhaps, is it too much to express a hope that we may soon be able to hail with the poet, as a sign of the returning spring, that

'Vulcanus ardens urit officinas.'

and may see

"The silent furnace once again in blast."

ON THE EXPANSION OF SEA-WATER BY HEAT.

By T. E. THORPE, Ph. D., and A. W. RUCKER, M. A.

Proceedings of the Royal Society.

The extensive contributions which have recently been made to the physical history of the ocean have shown the desirability of exact knowledge of the relations of sea-water to heat. We have accordingly thought it worth while to make observations in order to determine the law of the thermal expansion of sea-water.

The only attempt hitherto made to solve this problem which can lay any real claim to consideration is due to the late Professor Hubbard, of the United States National Observatory. The results of his investigation are contained in Maury's "Sailing Directions," 1858, vol. i. p. 237.

Muncke, nearly fifty years ago, determined the expansion of an artificial sea-water at various temperatures between 0° and 100°C.; but our confidence in the results as applicable to natural sea-water is affected by the circumstance that the solution was prepared from data furnished by the imperfect analyses of Vogel and Bouillon La Grange.

The observations of Despretz were confined to temperatures below 13°.27, as the main object of his inquiry was the determination of the point of maxi-

mum density of sea-water. The subsequent investigations of Neumann and Rossetti were equally limited, as they were undertaken with the same view.

The water used in our observations was collected from the Atlantic, in lat. 50° 48′ N. and long. 31° 14′ W.; and its specific gravity at 0° C., compared with distilled water at the same temperature, was found by the bottle to be 1.02867.

The method of experiment was precisely the same as that already employed by one of us in determining the expansion of the liquid chlorides of phosphorus. It was essentially that already used by Kopp and Pierre; *i. e.* the expansion was observed in thermometer-shaped vessels (so-called dilatometers), graduated and accurately calibrated.

Three of these instruments and two sets of thermometers were employed. The latter were made by Casella; the length of a degree in different instruments varied between 9 and 13 millims.; they had been compared (the one set directly, the other indirectly) with Kew Standards.

Three perfectly independent sets of observations were made with the water in the state in which it was collected; and as Mr. Buchanan, of H. M. S. 'Challenger,' has found that the specific gravities of different sea-waters lie between the extreme values 1.0278 and 1.0240, and since, in order to be of value in the investigation of the physical condition of the ocean, the observations on their values and the formulæ of reduction ought to be correct to the fourth decimal place, we diluted quantities of our sea-water with distilled water, so as to have specimens of approximately the specific gravities of 1.020 and 1.025; and we concentrated a third quantity by evaporation until its specific gravity was increased to 1.033, and made two series of independent observations on the expansion of each solution.

As we wished to confine ourselves to circumstances to which sea-water is naturally exposed, we did not carry on our experiments at temperatures higher than 40° C.

Empirical formulæ were calculated to express the results of each series of observations; and in the original paper full details of the observations are given, together with Tables showing the agreement between the calculated and observed results, and also (after the necessary corrections and reductions have been made) between the volumes calculated from the formulæ from different series of observations on the same solutions.

Finally, a general formula of the form

$$v = \Phi(t) + \chi(t) f(s)$$

was found, giving the relation between the volume (v), temperature (t), and specific gravity at 0° C. (s) of any solution of the same composition of sea-water the specific gravity of which at 0° C. lies between 1.020 and 1.033, the volume at the same temperature being taken as unity; in which expression

$$\Phi(t) = 1 + .00008097\, t + .0000049036\, t^2 - .000000012289\, t^3.$$

$$\chi(t) = -10^{-5}(.5509\, t - .020198\, t^2 - .00033276\, t^3),$$

and

$$f(s) = 11.95 - 940\,(s - 1.02).*$$

In the original paper we show that if Σ be the specific gravity at any temperature t of a solution the specific gravity of which at 0° C. is s, we may without sensible error assume $\frac{d\Sigma}{ds}$ to be constant; whence, by means of the above formula, we are able to give in the following Table all the data necessary for calculating the specific gravity of sea-water of any degree of salinity at any temperature between 0° and 36°. Column II. contains the specific gravities at the temperatures given in Column I. of a solution the specific gravity of which at 0° C. is 1.02000; Col. III. contains the numbers which must be subtracted from those in Column I. for each increase of 0°.1 over the temperatures opposite to which they are placed; and Column IV. the numbers which must be added for each increase of .00001 of the specific gravity of the solutions at zero. At the heads of Columns III. and IV. are the numbers of ciphers which must be prefixed to the figures written in them in the unit place.

* The numerical constants involved in the above formula are given in the forms in which they were, for facility of calculation, determined. The expression can of course be easily transformed to the simpler form, $v = F_1(t) + s\,F_2(t)$.

Temperature.	Specific gravity.	Proportional parts for 1° C.	Proportional parts for .00001 increase in spec. grav.	Temperature.	Specific gravity.	Proportional parts for 1° C.	Proportional parts for .00001 increase in spec. grav.
°		.0000	.0000	°		.0000	.0000
0	1.02000	3	1	19	1.01740	25	0 944
1	1.01997	4	0.995	20	1.01715	25	0.943
2	1.01993	5	0.990	21	1.01690	26	0.941
3	1.01988	6	0.986	22	1.01664	27	0.940
4	1.01982	8	0.932	23	1.01637	28	0.938
5	1.01974	9	0.879	24	1.01609	29	0.937
6	1.01965	11	0.975	25	1.01580	29	0.935
7	1.01954	12	0 972	26	1.01551	30	0.934
8	1.01942	13	0.969	27	1.01521	30	0.932
9	1 01929	14	0.966	28	1.01491	31	0.930
10	1.01915	15	0.963	29	1.01460	32	0.928
11	1.01900	17	0.961	30	1.01428	32	0.925
12	1.01883	17	0.958	31	1.01396	33	0.922
13	1.01866	19	0.956	32	1.01364	33	0.919
14	1.01847	20	0.954	33	1.01331	33	0.915
15	1.01827	21	0.952	34	1.01298	33	0.912
16	1.01806	21	0.950	35	1.01265	34	0.908
17	1.01785	22	0.948	36	1.01231	34	0.903
18	1.01763	23	0.946				

In order to facilitate the use of the Table, we subjoin directions for its application in the form of rules, and give a couple of examples:

I. Given the specific gravity of a sample of sea-water at any temperature t, to find it at 0° C.:—Look out in Column I. the figure giving the number of entire degrees of the temperature; multiply the corresponding number in III. by the fraction by which the observed temperature exceeds that number, and subtract the results from the corresponding number in Column II. Subtract the difference from the observed specific gravity, and divide the number so obtained by that corresponding to the observed temperature in Column IV. without prefixing the ciphers at the top of the column); add the quotient to 1.02000, and the sum will be the specific gravity required.

Example I. Specific gravity observed at 18°.5 C.=1.02475. Number opposite 18 in Column. III. is .00023, which multiplied by .5 equals .00011; and

$$1.01763-.00011=1.01752.$$

Subtract this from the observed specific gravity,

$$1.02475-1.01752=.00723.$$

Divide by .945 (the number corresponding to 18.5), and the quotient is .00765, which added to 1.02000 gives 1.02765 as the specific gravity at 0° C.

Example II. Specific gravity observed at 15° C. = 1.02570.

$$1.02570-1.01827=.00743,$$

and

$$\frac{.00743}{.952}=.00780.$$

Therefore specific gravity at 0° C. = 1.02780.

We next discuss the discrepancies which occur between our own results and those of Professor Hubbard; and we point out various circumstances in the methods employed in making and reducing the latter observations which appear to us to explain in a great measure the divergences which exist.

A PROPOSAL is to be laid before the Austro-Hungarian delegations for facilitating the navigation of the "Iron Gate" on the Danube. The works will, it is estimated, cost about 6,000,000fl., and it is proposed to recover this amount by levying toll on all vessels that pass. The other Danubian States, viz., Turkey, Servia and Roumania, have already expressed their entire concurrence in the project.

ON THE COMPARATIVE MERIT OF SIMPLE AND COMPOUND ENGINES.

By G. B. RENNIE, Esq., M. Inst. C. E.

"Journal of the Royal United Service Institution."

Having been invited by the Council of this Institution to read a paper "On the comparative merit of simple and compound engines," I will endeavor to lay my views before you with as few technical expressions as possible. That such a subject cannot be treated altogether free of such terms, and as I expect that several members present here to-night are of the Navy, who have mostly a knowledge of the construction and management of the propelling machine on board a man-of-war, I trust your indulgence in allowing me the use of a few professional words.

It will *first* be advisable to understand what is meant by the terms simple and compound engines (those being the words given by your Secretary). As regards the "simple engine," it may be either taken as the simplest type of steam engine in ordinary use, such as with a single cylinder, without separate appliances for "cutting off" the steam to allow it to expand more than is due to the ordinary "cut off" made by the slide valve, and to discharge the steam so used direct into the atmosphere; or it may be considered an improved form where the steam is expanded to its utmost by the use of separate expansion-valves, or by utilizing the steam discharged by heating the feed water, or improving the draught of air in the furnace, by turning the discharged steam into the chimney by what is known as the "blast," or by condensing the discharged steam either by direct contact with cold water, or what is known as surface condensation, and finally taking advantage of the steam so condensed in creating a vacuum by the application of an air-pump to discharge the air and condensed steam. Though all these forms of engine, each of which is a gradual improvement on the efficiency of the machine, may be taken as the "simple" marine engine, yet I am inclined to think the latter, which may be considered as the most improved type of using the steam advantageously in a single cylinder, so as to get the greatest power out of a given quantity of evaporated water, is what would be most interesting to you to form a comparison with what is called the "compound" engine.

Secondly. The compound engine, in contradistinction to the ordinary or simple engine, has two or even more cylinders for using the same steam, that is, after the steam has done its duty in one cylinder, it is discharged into another, and in some few cases again into another, until the maximum effect is obtained out of the steam by its expansion.

The usual form of compound engine is to have only two cylinders in a complete machine, the two cranks being placed at right angles with each other, as with the "simple engine," but they are not unfrequently made with four cylinders, viz., one large and one small to each crank. The proportion of the large to the small cylinders in either system depends on the steam pressure used, the amount of its expansion, and whether especial mechanical arrangements are made for cutting off the steam by independent valves, or merely allowing the steam to expand, according to the relative volume of the two cylinders. The usual proportion is, however, three or four to one.

Examples of the first arrangement are the "Briton" and "Tenedos," similar ships of 350 nominal horse-power. The results of the trials of these two ships may be said to have commenced, the compound system being adopted in the Navy, though the "Sirius" and "Spartan," of similar horses' power, had been tried some time previously. These two are of the second type of compound engine above described, each crank having a large and a small cylinder working on it.

The results of the "Briton's" trials are published in the "Transactions of the Society of Naval Architects," from a

paper I read at a meeting of the Society held in March, 1871.* The consumption of coal at full power was slightly under 2 lb. per indicated horse-power per hour, the best result being obtained when working about half power, when only 1⅛ lbs. was burnt per indicated horse-power. A nearly similar result when working full power was obtained with the compound engine for driving the new pumping machinery at Chatham Dockyard. Arrangements were made for measuring all the steam used in the engines by discharging it, after it was condensed into water, into two tanks. The power by the indicator was taken every ten minutes. The total time of working the engines was a little over 3½ hours, and it was found that 18.92 lbs of water were used in the shape of steam per indicated horse-power per hour; and as the coal used, viz., "Fothergill's Aberdare," has, according to Admiralty experiments, an evaporative power of 9.73 lbs. of water per lb. of coal, this would give (taking the steam used as the basis of calculation) a little under 2 lbs. of coal per indicated horse-power per hour.

I have here a table of the comparative consumption of coal of different kinds of engines. This comparison was made a few years ago, and from further observations I think it is, on the whole, a pretty fair one.†

There may be many engines of each kind which may consume more or less than stated; but supposing them to be all under the same usual conditions, both as to manufacture, kind of coal, and other circumstances, I believe it is not far from correct.

Since this table was made out, I have had a most satisfactory opportunity of comparing the results of the coal consumed between the ordinary or simple injection engine working with 25 lbs. steam in the boilers, and the same engine, after being compounded, working with about 55 lbs. steam in the boilers.

The "Minia," was a screw steamer of 200 nominal horse-power. The cylinders were 54 inches diameter, with a stroke of 3 feet 4 inches. The number of revolutions of the screw propeller was about 60 per minute. The engines were the ordinary overhead construction, with injection condensers and boilers for working with 25 lbs. steam pressure. The

* *Particulars taken from the Reports of the Official Trials of the Compound Engines of H. M. S. "Briton" for six hours' steaming.*

Date of Trial.	Mean speed of ship in knots.	Pressure of steam in engine room.	Revolutions per minute.	Indicated horse-power.	Coal per horse-power per hour.	Time of steaming with 240 tons.
2d June	12.767	51.91	92.649	2,018.3	1.98	5½ days.
10th June	10.026	50.00	67.308	660.58	1.3	26 days.

† *Comparative Consumption of Coal of different Types of Engines.*

Type of Engine.	Per H. P. per hour.	Tons per diem.	Days and Hours steaming with 240 tons of coal.	
			Days.	Hours.
1. Improved compound	2¼	48	5	0
2. Ordinary type with surface condensers and superheaters	3½	75	3	4
3. Ordinary injection	4½	97	2	11
4 High pressure	6	129	1	21

average consumption of coal was at the rate of 33 tons per 24 hours, with a maximum consumption at full power of 45 tons per diem. The engines were "compounded" by my firm, by placing small cylinders of 27 inches diameter on the top of the existing cylinders. A surface condenser was also added, and one of the existing air pumps was converted into a cold water circulating pump. Four new boilers, adapted for 60 lbs. working pressure, were also supplied. The rest of the engine, including the screw-propeller, remained as before, and the result has been that the average consumption at sea has been reduced to 17 tons per diem (equal to about 2¼ per indicated horse-power), with a maximum consumption of 24 tons when working full power, and the revolutions of the screw propeller, and consequent speed of ship, has been slightly increased. That is, the coal consumption has been reduced nearly one-half since the engines have been "compounded."

I may also cite another example of the comparison between the ordinary injection engine and a new compound engine which had been substituted for it. The "Pera," a screw vessel belonging to the Peninsular and Oriental Company, had formerly vertical geared engines of the injection type, which were considered very economical in their day.

The nominal power was 450 horses, and gave an average yearly speed of 10.4 knots per hour, with a consumption of 43 tons per diem. New engines were placed on board, of the compound type, and the ship ran from Brindisi to Alexandria, with the Indian mails, making an average somewhat over 10½ knots, with an average consumption of about 24 tons of coal per diem. This is an example where both engines are by the same makers, with equally good manufacture, and the same engineer management on board, and the ship navigating the same seas.

As an instance what can be done in making a long sea voyage entirely under steam, with a small-sized ship with compound engines, I may mention that of a dredging vessel of 160 feet in length, and 28 feet beam, fitted with twin screws and compound engines of 70 nominal horse-power, having made the voyage from London to Buenos Ayres in 46 days, stopping only once, namely at Madeira, to fill up with coal; that she steamed a distance of about 5,000 miles, between Madeira and Buenos Ayres, in 36 days, without taking in fresh coal. Had the ship had the old class of engines, she would have been obliged to have made the voyage under canvas, or to stop at intermediate ports to take in coal.

It will be understood that such a radical change in the propelling machine of a ship, enabling her to be steamed nearly double the distance with the same weight of fuel, is so important in its effects on ocean steam navigation, that one can hardly be surprised at the demand there has been in the mercantile world for ship engines of the new type; but the increased number of steamers and accelerated trade thereby, so increased the demand for coal, which was not supplied in the same rapid rates as the ships and engines, and so augmented the price of it, that the money equivalent from the reduced amount of coal used in each ship has not been realized to what was expected, and has unfortunately now caused a considerable stagnation in the shipping trade.

The improved result in point of consumption of coal of the compound engine over the old type engine, is not due entirely to making the steam do duty in two cylinders instead of one, but to the different conditions in which the steam is used, viz., to the greater boiler and initial pressure used in the cylinders, and to expanding it to a much greater extent than formerly, in order to get the full duty out of it. The question of the relative advantage of expanding steam in one cylinder or two has been a controverted one with engineers for many years, especially as regards land engines, where the higher pressures had been more frequently used; but I think it is now pretty well agreed on all sides by those who have studied the subject, that where the pressure of steam, amount of expansion of same temperature, and dryness being also alike, and with equally good manufacture and superintendence, that the fuel consumed per indicated horse-power, is practically identical in both systems.*

* That is, when the pistons are of so good a construction as to be practically tight; but should that not be the

We have adopted the compound engines for many years; in 1842 we supplied them for Messrs. Cubitt & Sons, London Dock pumping engines, Royal Arsenal, and many others. The engines on this plan are usually called "double cylinder beam engines," and work with about 60 lbs. in the boilers; our preference for this engine being that the strains were more uniform and less severe, and the rotatory motion more equal. The consumption of coal I find in referring to some old examples, was about 2¼ lbs. per indicated horse-power, or about the same that is realized in a good compound engine.

It is always a difficult matter to get good examples of a fair comparison between two classes of engines, but as regards land engines, I may quote the trials between the simple and compound engines made at the New River Waterworks Company, where, I believe, as far as consumption of coal was concerned, there was practically no difference in the two systems. As regards marine engines, the comparative trials between the "Goshawk" compound and the "Swinger" simple, with two cylinders of equal size, will be in the recollection of many, but it may be well to state the leading particulars. These two vessels were of like tonnage and horse-power, the trials were of six hours' duration, and took place at the same time and place. The average power of the "compound" was 374.2 horses, at a consumption of 2.6 lbs., and the "simple" was 364 horses, at 2.61 lbs. per square inch. After the trials to test the coal were completed, the speed of each vessel was ascertained on the measured mile, which showed the "compound" vessel to be making 10.419 knots, whilst the "simple" only made 10.14 knots. The greater speed of the former may probably be due in part to a slight excess of engine power; but I am inclined to think that more is due to the more uniform distribution of the power round the path of the crank, and that that machine which gave the more steady and uniform motion to the propeller, pushed the ship the fastest through the water.

The compound engines of the "Briton" I found to be even more uniform than those of the "Goshawk"; the pressures in that case varied from 7.91 tons to 17.16 tons, or the highest was only 2.1 times that of the lowest.

I believe the question of a uniform tangential force is of more importance than is often considered, both for propeling the ship, as well as for the less liability to rupture of the different working parts which rupture is more often due to suddenness and change of strain than to a constant steady pressure.

Taking the above named pressures in each class of engines, I found by keeping the shafts and other working parts of equivalent strength, which would probably give a total weight of somewhat under five per cent. for the pressures they had to sustain, that the simple engine was about one-tenth heavier than the compound engine, of course, irrespective of boilers, which would be common to both.

To show how important it is to take into consideration the tangential forces in the crank-path, I found, in making different calculations for finding the best position to place the cranks of the compound three cylinder engines of the "Boadicea" and "Bacchante," of 5,250 horse-power each, that if the cranks were placed at equal angles between them, the shaft should be 18 inches diameter, but if placed with the two low-pressure cranks opposite to each other, and the high-pressure crank at right angles to them, that the shaft need not be more than 16 inches to be of equal strength to transmit the same total power.

The *simple engine*, or engine with two cylinders of the same size, working with a pressure of from 60 to 70 lbs. direct on the pistons, has been tried in more than one Transatlantic Company. One of them had, I believe, four vessels with such engines, but it was eventually found necessary to reduce the pressures some 20 lbs. per square inch in consequence of the crank-shafts continually breaking, but, according to the usual mode of calculating the strain on the shafts, they ought to have been amply strong enough

case (which is not uncommon) I think it highly probable that with the simple engine, with 60 or 70 lbs. on one side of the piston and a vacuum on the other, a much larger consumption of steam and coal will take place than with the compound cylinders, where the pressure is at the boiler pressure on one side of the piston, and some 5 or 10 lbs. above atmospheric pressure on the other; moreover, should any leakage of steam take place by the high-pressure piston, it will have a chance of being used in the low-pressure cylinder before being discharged into the condenser.

for the intended pressures, and I can only account for it by the sudden and irregular strains on the shafts due to the high initial pressure and early "cut off."

It has been supposed by some that the weight of the screw propeller is sufficient to act as a fly-wheel to give an equitable rotative motion in propelling the ship; but I think that any one who has observed the working of a powerful engine on board ship must have seen that such is not the case: there is usually one part of the revolution of the shaft that appears to have greater power exerted through it, and it is felt in the motion of the ship. It has always appeared to me that I have felt less motion with the compound engine than with the old type.

One objection that has been used with reference to the compound engine is, that the low pressure cylinders in engines of great power become of so large a size as to render the castings excessively heavy, and that many of them have cracked after being in use. This difficulty is in a great measure obviated by making an inside liner of a separate piece from the body of the casting, and forming a space between them for a steam jacket, instead of casting the whole in one. The system of having two low-pressure cylinders to one high-pressure cylinder, as in the "Boadicea," or by having two low-pressure cylinders and two high-pressure cylinders, as in the "Minia" type, also prevents any objection on that score.

It has been sometimes asserted that the increased surface subject to radiation in the compound cylinders has tended to a loss of heat; but on the other hand it must be remembered that the increased size also gives an increased surface of steam jacketing to warm up the steam inside the cylinder.

Some interesting particulars have lately been published with reference to the trials made with the engines of the United States' Coast Survey steamer "Bache." These seem to have been made with and without a steam jacket on the compound cylinders compared with the same pressure of steam (80 lbs. per square inch), used in a single cylinder alone, also with and without the steam jacket. The high-pressure cylinder was about 16 inches diameter, and the low-pressure 25 inches, stroke in both being 2 feet. The results, *without steam* in the jackets when working as a compound engine, appear to indicate that there is not any material difference in the consumption of steam and coal per indicated horse-power by using the different grades of expansion, which varied from 5.6 to 9.14 times total expansion, with a consumption of coal only varying from 2.54 lbs. to 2.6 lbs. per indicated horse-power per hour. Whereas when the single large cylinder alone was used without the steam jacket admitting the steam pressure of the boiler, viz., 80 lbs. per square inch, direct on to the piston and "cutting off" by means of an independent valve, the consumption per indicated horse-power appears to increase when the expansion of the steam is greater, that is, with a ratio of expansion varying from 5.3 to 11.8 times. The coal per indicated horse-power varies from 2.874 lbs. to 3.84 lbs.; but when steam was admitted into the jackets (and selecting two trials from each series of experiments which more favorably compare), the compound cylinders had a ratio of expansion of steam of 5.7 and 9.19, with a corresponding consumption of coal of 2.23 and 2.26 lbs. respectively, and with the single with steam in the jacket with an expansion of 5.1 and 8.57 times and a consumption of 2.53 and 2.638 respectively, that is, the result is rather in favor of the compound engine in point of consumption of steam and coal. That this is due to any advantage of expanding the steam in two cylinders instead of in one I am not inclined to think, but probably to some difference in the vacuum, coal, or stoking, besides the slight difference in the expansion, or to leakage of steam by the piston.

The initial pressure on the large piston, after the steam has done its duty in the small one, is given as 18.99 lbs. (say 20 lbs.), but when the steam is acting direct on the large piston for working on the simple plan, then the initial pressure is as high as 90.14 lbs. (say 90 lbs.), the average revolutions in the first case being 48 and the second 46½, the horse-power being 77.45 and 74.6 respectively.

It may therefore be said with the same horse-power and same number of revolutions that the total pressure on the compound cylinder would be 1 and on

the simple cylinder 4½; but supposing—to fairly represent the difference—there were two cylinders at half the size to compare with the two cylinders of the compound engine, the proportion of the pressures would be as 2¼ to one, and the working parts would have to be increased at least in corresponding proportion to be of equal strength to the parts of the compound engine.

In actual practice in marine engines, it may happen that the smaller diameter of the "simple engine" may be still further reduced, in consequence of the form of the ship admitting of the cylinders being placed more in the wing, which may still further enable the diameters to be reduced and the stroke increased in proportion.

It seems to me that the compound engine must be looked on in the light of a most convenient mechanical arrangement for working with a high pressure of steam and great expansion; and should very much higher pressures than 60 or 70 lbs. per square inch come into use—and I believe it has been proposed to make some engines for the navy for working with from 250 lbs. to 300 lbs. pressures—it seems to me that some system of compound must of necessity be adopted, and that with three or more cylinders in lieu of two, as is now usual.

The following, I therefore think, may be the summary of the comparative merit of the simple and compound engine:

1st. With equal amount of pressures, expansion, dryness of steam, the coal consumed will be practically identical in both systems, supposing the pistons tight.

2nd. When equal power is obtained, the working parts of the simple engine will have to be heavier than the compound.

3rd. The strains on the compound engine being more uniform, there will be less liability to fracture in the working parts.

4th. The simple engine with two cylinders of the same size will have the advantage of having fewer pieces of spare gear to stow away.

5th. The simple engine having each cylinder independent of the other can be more readily worked with one engine than with the compound engine, should one engine be disabled.

6th. For the same power of engine, it is probable that a greater speed of ship may be obtained with the compound engine than with the simple engine.

7th. If much higher boiler-pressures come into use than are now usually worked, the compound engine will have to be exclusively adopted, on account of the better mechanical arrangements which can be made for working with a high degree of expansion.

Iron Ore in the South of Russia.—These new fields (recently discovered) of beautiful iron ore are situated partly in the Verchni-Dnieprovsky district of the Ekaterinoslaw Government, partly in the Elizavetgradsky district of the Cherson Government; iron ore is found here on the rivers Saksagane and Ingouletz, near the village Krivoy-Rog. About twelves miles from this place on the river Saksagane, near the village Tchervonnaia-Balka, large quantities of red hæmatite are found. Immense layers of hæmatite, 100 feet thick, are situated near the river Ingouletz and the village Doubovaia-Balka. The best layers of iron ore are the following:

(1) On the left side of Ingouletz and on the right of Saksagane, between the village of Kirvoy-Rog and Doubovaia-Balka, is a layer of ironstone 120 feet thick; the results of the analyses are: Oxyde of iron, 68.40 per cent.; manganese, 0.50; silica, 22.10; alumina, 3.00; lost from ignition, 6.00 per cent.; total, 100.00.

(2) On the left side of the river Saksagane a layer of red hæmatite 42 feet thick; gives 62.5 per cent. of oxyde of iron.

(3) On the same river Saksagane exist layers of magnetic iron ore and of brown hæmatite; a sample of the latter analyzed gave the following average composition: Oxyde of iron, 73.40 per cent.; manganese, 1.30; silica, 18.03; alumina, 2.25; lost from ignition, 5.02; total, 100.00 per cent.

It is estimated that the new fields of iron ores contain altogether 90,000,000 tons of ore. There is a railway going to be constructed to these mines, and some blast-furnaces are to be erected.

THE BEHAVIOR OF METALS UNDER REPEATED STRAINS.

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I.

In vols. X., XIII., XVI. and XX. of the *Zeitschrift f. Bauwesen* are published the experiments of A. Wöhler upon the strength of iron and steel, with a description of the apparatus used, a statement of his views of the laws, and a mathematical comparison of the different kinds of resistance. Afterwards Wöhler, induced by the novelty of the results obtained, requested the Industrial Bureau to authorize the repetition of his experiments. At the suggestion of Prof. Reuleaux, the writer was intrusted with the investigation.

We quote the laws deduced by Wöhler, and give a brief account of his processes. He says :

"Rupture of material may be caused by repeated vibrations, none of which attain the absolute breaking limit."

Assuming the lower limit of tension at zero, it follows from this law that the number of repeated strains necessary for rupture is inversely proportional to the greatest tension borne by the fibres which are subject to greatest strain.

Wöhler's apparatus was of four kinds:

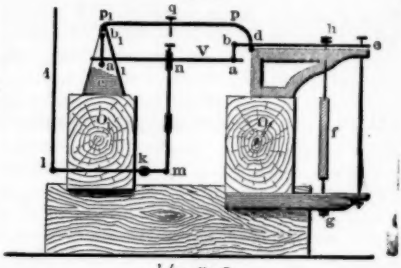
(1) For rupture by repeated load.
(2) For repeated bending in one direction of prismatic rods.
(3) For experiments on loaded rods under constant bending strain.
(4) For torsion by repeated load (strain).

The power was transmitted by a shaft to (1), (2) and (4) by means of an eccentric ; to (3) by a drum on a steel shaft having ends with conical bores, into which the piece subjected to torsion was fastened with an apparatus of screws.

Apparatus (2) is shown in the diagram (Fig. 1).

The rod to be tested rests upon the supports a and a, which are connected with the link pieces $a\,b$ and $a_1\,b_1$; the latter turning at b_1 in the cast iron block c ; the first being attached to the short arm of the lever $b\,e$. The spring dynanometer f, which can be stretched within certain limits by screws at g and h, prevents the long arm from rising when the short is loaded. The strain is applied by means of the eccentric-rod i. This is connected with the lever $l\,m$, whose fulcrum is at k ; so

FIG. 1.



1/36 n. s.

that when the rod rises the end m descends, and transmits a bending strain through $m\,n$ to the rod V, then to b and b. Six of these machines are set upon the beds O and O ; so as to be operated by the same rod i. If each of the six test rods is to be subjected to maximum strain, the dynanometer f operates as follows :

Let S = the required maximum tension per square unit.
b = the width of the test-rod.
h = the depth of the test-rod.
$a\,a_1 = l$.
P = the required strain at the middle ; then we have

$$P = \frac{4}{b} S \frac{b h^2}{l}$$

This force is borne equally at a and a_1, so that $\frac{P}{2}$ at b acts downward, and is balanced by the tension S of the dynanometer and the excess of weight of the rod $d\,e$. If H is the weight of the lever reduced to the point h, then $\frac{b\,d}{d\,h} = \frac{1}{n}$

$$\text{And } S = \frac{P}{2n} - H.$$

As long as the *f* strain *k* on *m n* is less than P, the point *a* must be regarded as fixed, and the rod V bends; but when *k* is greater than P, the point *b* yields, and while the rod is under bending strain there is a rotation of V about a_1, which is shown at the end of the lever *e*.

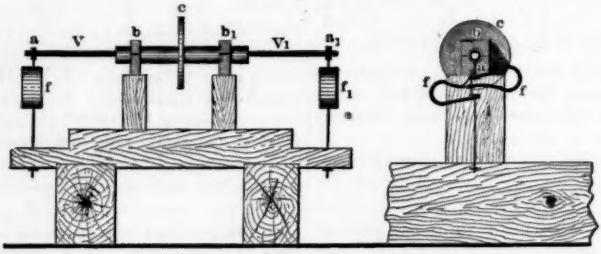
The rod *m n* has at the top a stirrup through which passes the rod to be tested; and at the lower end is a slot in which is fixed a pin attached to the lever *l m*, so that when the rod *i* rises a downward pull is caused; but when it descends the rod is set free and is restored by its own elasticity to its first position. In the middle of the rod *m n* is a screw with a nut to adjust the length, so that only for a moment before the point *n* reaches its lowest position, does the point *a* descend. The tension is therefore maintained for a very short time.

If the tension is to be restored, not to zero, but to some minimum value, the screw *q* is set down so as to keep the rod bent the required amount.

In a similar way the limiting strains in apparatus (1) and (4) are determined, while in (3) the constant deflection of the rod is produced by a spring dynanometer *f* (Fig. 2).

Each fibre, except those lying in the neutral plane, was subjected first to compression, then to tension.

FIG. 2.



$^1/_{36}$ n. s.

Wöhler, after testing a metal to the limits of elasticity and rupture in the ordinary way, had rods made of the same metal, and subjected the first test-rod of each set to a tension nearly equal to the absolute rupturing strain. Each successive rod of the same set of experiments was subjected to a diminished strain. It appeared that the number of strains required for rupture increased much more rapidly than the strains diminished.

Diminish the intensity of the strains until the number is reached which a member of any structure, subjected to repeated stresses, may bear before becoming crippled, and introduce a safety factor $\frac{1}{n}$ (which Wöhler makes $\frac{1}{2}$) and we have the value of the permissible strain. The *practical* proof strain is thus directly determined.

Wöhler found that a rod of Krupp's cast steel, under a maximum tension of 300 Ctr. per square inch (German), was broken in apparatus (3) after 4,500,000 revolutions. If this metal were used in an axle which had to make 30,000 rotations per day, or 9,000,000 per year; then for five years' duration (with coefficient $\frac{1}{2}$), the working strain would be 150 Ctr. per square inch. Another experiment showed that a rod of Phœnix iron after a maximum strain of 160 Ctr. per square inch after 132,250,000 revolutions was still in working condition. Wohler concludes that the working strength of iron suffering alternate compression and tension is 80 Ctr. per square inch, for a structure intended to be permanent.

Numerous experiments establish Wohler's second deduction that:

Differences of strains at the extremes of vibration are a sufficient cause of rupture of continuity; and the absolute magnitude of extreme strain is effective only in this respect; that as the strain increases the differences which are sufficient to cause rupture become less.

The experiments show that vibrations may take place between the following

limits of strength with equal security against rupture by tearing or crushing.

Iron	bet. + 160 Ctr. and — 160 Ctr.	
	bet. + 300 Ctr. and — 0 Ctr.	
	bet. + 440 Ctr. and + 246 Ctr.	

Strain per square inch.

Axle Steel Cast.	bet. + 280 Ctr. and — 280 Ctr.	
	bet. + 480 Ctr. and 0 Ctr.	
	bet. + 800 Ctr. and + 350 Ctr.	

Strain per square inch.

Spring Steel not hardened.	bet. + 500 Ctr. & 0 Ctr.	
	bet. + 700 Ctr. & + 250 Ctr.	
	bet. + 800 Ctr. & + 400 Ctr.	
	bet. + 900 Ctr. & + 600 Ctr.	

Strain per square inch.

And for shearing resistance:

Axle Steel Cast.	bet. + 220 Ctr. & — 220 Ctr.	
	bet. + 380 Ctr. & 0 Ctr.	

Shearing stress per square inch.

Pieces which are subjected to alternate pull and thrust, as piston rods, &c., must be about 9.5 stronger than those bearing but one kind of stress.

In the *Zeitchr. f. Bauw.* for 1870, p. 87, Wohler says:

"The results of the experiments give the following working strains for permanent structures:—(*a*) For forge iron strained in both directions 80 Ctr. per square inch; in one direction, 180 Ctr. per square inch, of which 150 Ctr. at the most may be due to the variable load.

"If the constant strain is less than 30 Ctr., the permissible working strain is diminished.

"(*b*) For cast steel not hardened, strained in both directions, 120 Ctr. per square inch; strained in one direction, greatest total strain 330 Ctr. per square inch, of which 220 Ctr. at most may be due to the variable stress. (The figures apply only to dressed rods.")

Having given an account of the nature and results of Wohler's experiments and of his conclusions, we now pass to our own experiments.

In November, 1872, we tested the Phosphorbronze of Künzel from Hoper's Works at Iserlohn. At the same time tests were made of common bronze from the Neptune Continental Works. The results are given in Tables III., VI. and IX.

In 1873, we received 52 cast steel bars from Krupp, cut by him from a locomotive axle; the results of experiments on these are given in Tables II. and VIII.

Few experiments could be made with Machine IV., because but one bar could be tested at one time. But the results are worth recording (Table IX.), because they indicate a valuable property of phosphorbronze.

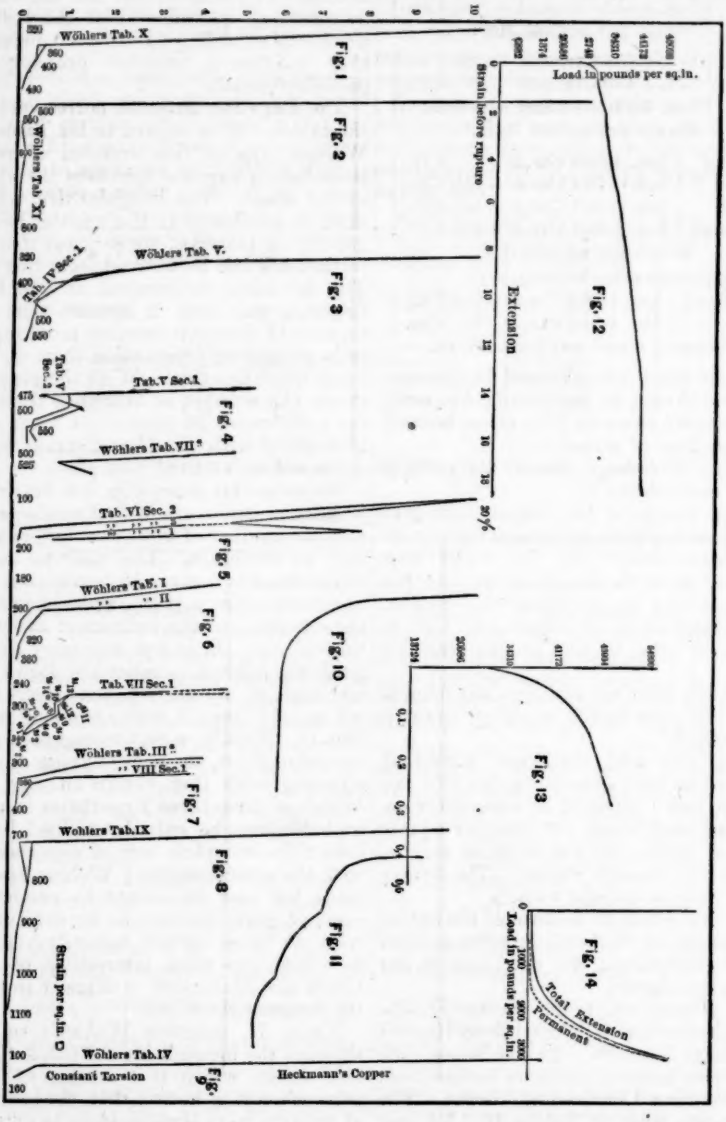
The diagrams annexed correspond to the tables. With regard to his Table I., Wohler says:—"The number of rotations before rupture increases inversely as the strain. The irregularities, which must be attributed to the want of homogeneity of material, are so great that no certain law can be derived from this set. The deviation is greatest at 220 Ctr. Ignoring this case, it appears that the number of rotations increase more rapidly in geometric progression than do the loads in arithmetical. With the greatest strain the number of rotations doubled for a difference in load of 24 Ctr.; and it doubled with the lowest strain for a difference of 10 Ctr."

To make this clear, Fig. 6 is drawn, in which the strains are laid off as abscissae, and the number of rotations before rupture as ordinates. This may be easily represented as a curve by leaving out the uncertain point u (220), and connecting the extremity of the ordinate of 240 with that of 200. It is not necessary to regard the point u as taken too high; for although u, would be too low, still we should have a curve agreeing with Fig. 10. Finally, u may be regarded as a reversion-point, the curve having a form agreeing with that shown in Fig. 11. Which of these three hypotheses is most probable can be only determined by at least three complete sets of experiments with the same material; Wohler having made but one set, except in particular cases of great doubt. As we shall often refer to these curves, we only remark here that the most interesting of the tables are illustrated in Figs. 1 to 9 on the diagram sheet.

Table II. contains Wohler's results showing the inequalities of Firth & Sons' tool steel; which is a matter of surprise when it is known that the sections of rupture were homogeneous in appearance. We attribute the fact to the presence of a large percentage of carbon; the steel being intended for tools, not

for axles. For this reason we have not subjected it to continued torsion.

A decided difference in hardness appeared in rods 3 and 4; so that the remainder were heated dull-red, and were cooled slowly under warm ashes, so that the hardness was made more uniform without affecting the strength.



Tables III. and IV. show that Kunzel's phosphorbronze has much more strength than common bronze and brass. Wrought, *i. e.* cold-beaten phosphorbronze does not seem to have as much strength as that which is cast. Wrought phosphorbronze

shows a very rough, irregular fracture, while the cast breaks with a surface like that of cast-steel, indicating homogeneity of material. In this respect, common bronze and brass more resemble iron. Brass is hardly on equal terms with phosphorbronze in respect to absolute strength; there is a closer equality in

A. Repeated Stretching. I. to III.

Table I.

1872–4. Westphalia Iron.			Wohler's Tab. X. Phœnix Iron.	
No.	Maximum Strain per square inch Ctr.*	No. of rotations before rupture.	Maximum Strain per square inch Ctr.	No. of rotations before rupture.
1	480	4700	480	800
2	440	83199	440	106910
3	440	33230	—	—
4	400	136700	400	340853
5	400	159639	—	—
6	360	180800	360	409481
7	360	596089	360	480852
8	360	433572	—	—
9	320	280121	320	10141645
10	320	566344	—	—

* The Centner (Ctr.) = 110 lbs. English. | 9 and 10 showed welding joints.

Table II. Steel.

1872–4. Firth & Sons' Steel.			Krupp's Axle Steel.		Wohler's Tab. XI. Krupp's Axle Steel.	
No.	Max. Str. per sq. in. Ctr.	No. of tensions before rupture.	Max. tens. per sq. in. Ctr.	No. of tensions before rupture.	Max. Str. per sq. in. Ctr.	No. of tensions before rupture.
					800	18741
			640	81400	700	46286
1	600	83319	—	—	600	170000
2	550	168396	—	—	550	123770
3	500	133910	500	429000	500	473766
4	500	185680	—	—	—	—
5	500	360235	—	—	—	—
6	500	186005	—	—	—	—
7	490	103540	—	—	—	—
8	490	Sound after $12_{,2}$ Mil.	—	—	—	—
9	480	229230	—	—	480	Sound after $13_{,6}$ Mil.
10	480	692543	—	—	460	Sound after $12_{,2}$ Mil.
11	460	Sound after $12_{,2}$ Mil.	—	—	—	—

1 and 2 and 5–11 were heated a little and cooled very slowly; 3 and 4 were as they came from the rolling mill.

respect to bending. With axial strain, common bronze and brass broke at 200 resp. 150 Ctr. maximum fibre tension when the tension rod was shortened; but under transverse load with equal maximum tension, they bore millions of

stresses. It is obvious that it is not safe to infer that the behavior of a metal will be the same under different kinds of strain. Hence, we cannot agree with

TABLE III. BRONZE AND BRASS.

a. Phosphorbronze (unworked).			*b.* Phosphorbronze (wrought).		
No.	Maxi. Strain per square in. Ctr.	No. of rotations before rupture.	No.	Max. Strain per square in. Ctr.	No. of rotations before rupture.
1	250	147850	—	—	—
2	200	408350	1	200	53900
	—	—	—	—	—
3	150	2731161	2	150	Sound after $2_{,6}$ Mil.
4	125	1548920	3	125	1621300
5	125	2340000			
No. 3 was very hard.					
c. Common Bronze.			*d.* Brass.		
	—	—	—	—	—
1	200	0	—	—	—
2	200	4200	1	200	0
3	150	6300	2	150	0
4	100	5447600		100	53000
No. 1 broke by shortening of tension rod before 200 Ctr.			1 and 2 broke before 200 and 150 Ctr.		

B. REPEATED BENDING IN ONE DIRECTION. TABLE IV. TO VI.

TABLE IV.

Westphalia Iron.			Wohler's Tab. V. Phœnix Iron.		Wohler's Table VI. Homogen. Iron.	
No.	Max. Str. per sq. in. Ctr.	No. of bendings before rupture.	Max. Str. per sq. in. Ctr.	No. of bendings before rupture.	Max. Str. per sq. in. Ctr.	No of bendings before rupture.
	—	—	550	169750	—	—
	—	—	500	420000	—	—
1	475	612065	—	—	$^{800}/_{400}$	475500
2	450	457229	450	481975	$^{700}/_{300}$	1234600
3	425	799543				
						Sound after
4	400	1493511	400	1320000	400	34500000
5	360	3587509	360	4035400		
				Sound after		
			330	3420000		
				Sound after		
			300	48200000		

Wohler that it is sufficient to make experiments in one kind and deduce results for others.

Table IX. confirms our opinion Comparison of Tables III. with I. and II. shows that phosphorbronze under 250

Ctr. does not stand as many extensions as Phœnix or Westphalia iron under 400 Ctr. and steel under 600 Ctr. Comparing Table VI. with Tables IV. and V., we observe that phosphorbronze at 200 Ctr. tension does not bear as many bending strains as Westphalia, Phœnix or Homog. Iron at 400 and steel at 500 Ctr. The torsion tables show that phosphorbronze has a greater resistance to torsion than Krupp's cast-steel and Westphalia iron. This result was so surprising that we interrupted Test 3 in order to substitute the new rod of Test 4. Still we were in doubt, and therefore substituted experiment 5, which confirmed the previous results. Should further experiments give like results, then phosphorbronze, which is little affected by the action of sea water, must be employed in the axles of propeller screws.

The profiles of Fig. 5, correspond to

TABLE V. STEEL.

1872–4. Firth & Sons' Steel.			1873–4. Krupp's Axle Steel.			Wohler's Table VII. *a*. Krupp's Axle Steel.		Wohler's Table VII. *b*. Bochumer Verein Axle Steel	
No.	Max. Strain per square in. Ctr.	No. of bendings before rupture.	No.	Max. Strain per square in. Ctr.	No. of bendings before rupture.	Max. Strain per square in. Ctr.	No. of bendings before rupture.	Max. Strain per square in. Ctr.	No. of bendings before rupture.
								700	104300
						—	—	600	317275
1	575	281856	1	575	443800	—	—	—	—
2	550	2665[illegible]6	2	550	423400	550	1762300	550	612500
	—	—	3	525	513000	525	1031200	—	—
	—	—	—	—		520	1477400	—	—
3	500	1479908	4	500	1177400	500	5234200	500	729400
							Sou'd after		
	—	—	—	—		500	$40,_6$ Mil.	500	1499600
4	475	578323	5	475	1185100	—	—	—	—
					Sou'd after				Sou'd after
5	450	5640596	6	450	$1,_7$ Mil.	—	—	450	43 Mil.
		Sou'd after							
6	450	$13,_7$ Mil.		—		—	—	—	—
					Sou'd after				
			7	425	$1,_7$ Mil.	—	—	—	—

1–5 incl. were heated a little, and cooled very slowly.

5 broke accidentally.

TABLE VI. BRONZE AND BRASS.

Phosphorbronze.			Common Bronze.			Brass.		
No.	Max. St. per sq. inch. Ctr.	No. of bendings before rupture.	No.	Max. St. per sq. inch. Ctr.	No. of bendings before rupture.	No.	Max. St. per sq. inch. Ctr.	No. of bendings before rupture.
1	200	862980	1	200	102650	1	200	253100
2	180	8151811	2	180	151310	2	180	1934400
								Sound after
3	150	5075160	3	150	837760	3	150	$5,_6$ Mil.
		Sound after			Sound after			
4	120	10 Mil.	4	120	$10,_4$ Mil.	—	—	—

Table VI. That of common bronze appears most regular, showing the material to be of good quality. According to Dr. Künzel (Polyt. Centralblatt, Jan.

1874,) when a phosphorbronze axle is heated to a low red heat a very soft alloy of tin and lead is melted out, leaving the axle hard and spongy. Perhaps in this phenomenon is to be found an explanation of the peculiar behavior of the metal in respect to torsion.

Table IV. (divisions 1 and 2) is represented in Fig. 3. Both polygons agree fairly, leaving out of notice rod 1, whose deflection number is obviously too large.

Fig. 4 corresponds to the first three divisions of Table V. The profile of division 1, is very similar to Wohlers Table VII., to which we shall recur. Frith's steel seems to have a resistance of about 20 Ctr. less per square inch than the older cast steel of Krupp.

Table VII. is represented in Fig. 6 While the first two profiles indicate greater uniformity and strength of homogeneous iron than of Phœnix iron, we found that for spindle iron it was hardly possible to work out a profile including the points from u_3 to u_{16}. We went through with 3 sets of tests between 280 and 340 Ctr., and through 2 sets with strains less than 280, taking differences of 20 Ctr. We hoped to obtain a polygon agreeing with Fig. 10, by taking the arithmetical mean of 3 corresponding rotation numbers; but were disappointed. The great difference in the positions of the points corresponding to the same strain, is due not only to the want of homogeneity in the iron but also to errors in determining the number of

C. Continued Loads. Tab. VII. and VIII.

Table VII. Iron.

1872–3. English Spindle Iron.			Wohler's Table I. Phœnix Iron.		Wohler's Table II. Homogen. Iron.	
No.	Max. Str. per sq. in. Ctr.	No. of rotations before rupture.	Max. Str. per sq. in. Ctr.	No. of rotations before rupture.	Max. Str. per sq. in. Ctr.	No. of rotations before rupture.
	—	—	—	—	380	31586
1	340	r_1 204200	—	—	340	94311
2	340	r_2 204400	—	—	—	—
3	340	r_3 147800	—	—	—	—
	348)		—			
4	320	402900	320	56430	—	—
5	320	911100	—	—	—	—
6	320	503500	—	—	—	—
7	300	384800	300	99000	300	161262
8	300	1035300	—	—	—	—
9	300	1064700	—	—	—	—
10	280	979100	280	183145	280	464786
11	280	1337700	—	—	—	—
12	280	1066000	—	—	—	—
13	260	1142600	260	479490	260	636500
14	260	595910	—	—	—	—
		Sound after				
15	240	6,1 Mil.	—	—	—	—
16	240	3823200	240	909810	240	3930150
		Sound after	220	3632588		
17	200	8,8 Mil.	200	4917992	—	—
		Sound after				
18	200	4 Mil.	—	—	—	—
			180	19186791		
				Sound after		
			160	132 Mil.		

rotations, caused by defects in machinery. After these were cured the following tests were made and accurately registered: viz. the last 2.7 millions of 16, 17, 18 and the last 2.3 millions of No. 16.

We now give attention to the several points u which give a profile probably correct.

The points u and u_3 fairly agree; but rod No. 3, under 340 Ctr. strain could

not be counted, because of an accident that increased the strain by 8 Ctr. In Wohler's Table I. u_6 and u_7 may be rejected, the first as too high, the second, as too low. Whether u_{13} or u_{14} is the more correct could not be determined by two experiments, but we have set u_{13} nearer u_{10} and u_{12}. Hence the profile in Fig 6.

In considering the possible errors, if the lowest points only are regarded the profile u_3, u_7, u_{14}, u_{16} results which seems probably correct. But the question must be settled by experiment.

Only the first two divisions of Table VIII. are represented in Fig. 7; the third showing too great differences, and the fourth not agreeing with the foregoing.

Both profiles are similar, except that

TABLE VIII. STEEL.

1873–4. Krupp's Axle Steel.			Wohler's Table III. Krupp's Axle Steel		Wohler's Tab. III. Bochumer Verein Axle Steel. 1863.		Wohler's Tab. III. Borsig Axle Steel. 1863.	
No.	Max. Strain per square in. Ctr.	No. of rotations before rupture.	Max. Strain per square in. Ctr.	No. of rotations before rupture.	Max. Strain per square in. Ctr.	No. of rotations before rupture.	Max. Strain per square in. Ctr.	No. of rotations before rupture.
	—	—	420	55100	—	—	—	—
1	400	367400	—	—	—	—	—	—
2	380	428250	—	—	—	—	380	157700
3	360	925800	360	127775	360	127775	360	239875
		Sou'd after						
4	340	4,9 Mil.	340	797525	340	342850	340	553850
		Sou'd after						
5	320	4,8 Mil.	320	642675	320	627000	320	1373225
—	—	—	320	1665580	320	20467780		
—	—	—	320	3114160	—	—		
		Sou'd after						
6	300	5 Mil.	300	4163375	300	2845250	300	1025625
						Sou'd after		
			300	45050640		57 Mil.		
					280	3558700		

the one corresponding to Krupp's new steel is much higher than that of the old, showing an improvement in the manufacture.

In No. 6 appears a more careful diagram of the experiments of Table VII., made with the hope of being able to deduce the equations of the curves. This has not yet been accomplished. The experiments of Wohler were for the most part with the Phœnix axle iron and with tool steel and cast-spring steel. His tests of rails by torsion (having a special object in view) are not important because they are not subjected to that kind of strain.

In our attempt to collect the results of experiments, we received valuable information from a paper by Launhardt (Zeits, des Arch.-und Ing.-Ver. Zu Hannover 1873, Heft. II.). He gives the name of working resistance to that (greatest) amount of strain which is not sufficient to break the material after an indefinite number of applications; and of original resistance (ursprungsfestigkeit) to the amount when the material is allowed to a strainless condition, instead of to some minimum strain. He regards the working resistance (a) as a function of the breaking resistance (b), the original resistance (u), or of the ratio

$$\frac{\text{S min.}}{\text{S max.}} = \frac{\text{Its own weight}}{\text{total load}}$$

and employs the formula

$$a = u\left(1 + \frac{b-u}{u} \cdot \frac{\text{S min.}}{\text{S max.}}\right)$$

With reference to Wohler's results for cast steel

$$a=500\left(1+\frac{6}{5}\frac{\text{S min.}}{\text{S max.}}\right)\text{ Ctr. per sq. in}$$

And for wrought iron

$$a=300\left(1+\frac{5}{6}\cdot\frac{\text{S min.}}{\text{S max.}}\right)$$

These formulas are of some practical value; but they would be more trustworthy if they had been derived by direct experiments on material for bridges.

Wohler's experiments have required a period of 12 years; and a time equally long would be necessary to obtain a complete set of parallel tests for bridge material, unless the curve equation for some material recognized as good could be obtained. It would then be necessary to try a few tests only of high strains upon any other metal in order to determine with respect to quality, homogeneity and resistance. For example; assuming Fig 6 as such a "normal curve" the figure shows that the second polygon (Hom. iron) corresponds to a stronger material than does the first, since the latter at 240 Ctr. strain shows just as many rotations as the former at 210 Ctr. And it may be conjectured that the working resistance of homogeneous iron is at least 190 Ctr., while that of Phœnix iron is 160 Ctr. If this is clear on a diagram to a very small scale, it would be more certain if the normal curve were known.

Of course the number of rotations u, of a material diminish when the strains increase and conversely. Hence we may assume $u=f\left(\frac{1}{S}\right)$. Substituting in the formula

$$y=A+Bx+Cx^2+Dx^3+\&c.$$

u for y and $\frac{1}{S}$ for x.

we have

D. Experiments with Rods bent in Two Directions.

Table IX.

Material.	No.	Maximum Strain per square inch. Ctr.	No. of rotations before rupture.
Westphalia Iron of 1872–4.....	1	240	431306 Crippled after
Firth & Sons' Cast Steel	2	240	6497800 Crippled after
Hammered Phosphorbronze.....	3	240–320	14916800
" "	4	300–360	4032680 Sound after
" "	5	360	1301600
Wohler's Table XIII.			
Krupp's 1862 Cast Steel		260 240	1007550 859700

Remarks.—No. 3 had borne under a strain of 240 Ctr.....7743000
Again under a strain of 300 Ctr.....3993800
Again under a strain of 320 Ctr.....3180000
14916800
And dynanometer allowed no higher strain.

No. 4 had a smaller diameter than No. 3, and had borne
Under 300 Ctr. strain.....1000000
Under 320 Ctr. strain.....1200000
Under 340 Ctr. strain.....800000
Under 360 Ctr. strain... 1032680
4032680
Before rupture.

$$u = A + \frac{B}{S} + \frac{C}{S^2} + \frac{D}{S^3} + \text{\&c.}$$

If we close this series say at the 4th term, the co-efficients A, B, C, D can be determined by 4 experiments. If more experiments, say 8, 12 or 16, were made, then they would be determined with greater accuracy by the method of Least Squares; remembering that if S is infinite $u = 0$ and, therefore, $A = 0$. As the experiments show that u increases either in simple or quadratic ratio if S diminishes arithmetically, at least 3 terms must be taken, so that we have

$$u = \frac{B}{S} + \frac{C}{S^2} + \frac{D}{S^3}$$

If Newton's or Lagrange's formula of interpolation is used, it is better to make $y = \frac{1}{u}$ and $x = S$, giving the equation $AS^2 + bS^2 + CS = \frac{1}{u}$; because the successive values of S can be taken with equal difference, so as to simplify the calculation. Whether the series so found is sufficiently convergent to determine the coefficients B, C, D from a few experiments so as to give trustworthy values for u, cannot be determined *a priori;* for the coefficients of safety must be first fixed by a great number of experiments.

Wohler's tables require a careful revision. First with regard to division No. 1, viz.:

For iron { bet. + 160 and — 160 Ctr. / bet. + 300 and 0 Ctr. / bet. + 400 and + 240 Ctr. }
Tension per square inch.

Both limits, + 160 and — 160, agree with Wohler's Table I. for continuous torsion and Phœnix iron; the corresponding rotation-number 132¼ million is regarded as "unlimited duration." If, according to Wohler (Zeits. f. Bauw., 1858, p. 446), the maximum duration of an axle corresponds to a run of 200,000 miles, and the circumference of the wheel makes 2,400 revolutions per mile, then 480 million revolutions are sufficient to wear out the axle. Now, it is not certain that rod No. 9 of Wohler's Table I., after 132 millions, would stand 348 million more; but it is probable; because for equi-different strains the number of rotations increases in a ratio higher than the duplicate, and the number of rod No. 8 is 19 millions. For axle torsion, these limits hold; but not for axle compression and tension, as in the case of piston-rods; for according to Wohler's Table X. a rod of Phœnix iron was torn apart under a strain of 320 Ctr. after 10,100,000 tensions, and therefore would not have borne alternate strains of tension and compression to the number of 10 millions. Hence, although in the tables, to ensure two-fold security for wrought iron strained permanently in both directions, the strain 80 Ctr. per square inch is assigned as permissible; still this can be accepted only for the co-efficient 2, which must therefore have another office besides that of compensating for the non-homogeneity of the material. In this regard Launhardt's coefficient ⅓ seems to be worth testing by further experiments; especially for iron when greater resistance is called for in one direction than in the other.

The limits 300 and 0 are derived from Wohler's Table V., rod 7, which was sound after 48 million bendings. The jump from 360 with 4 million to 300 with unlimited number, is somewhat conjectural; and the assumption is made probable only by Fig. 3. The assumption derived from Table X. that for 300 Ctr. strain the duration is "unlimited," because for 320 Ctr. strain rupture was sound after 100 million extensions, is not justified either by the table or Fig. 1; so that Wohler's assumption that the "original resistance," shown in bending, agrees with that shown in extension, requires the confirmation of experiment.

The third pair, + 440 and + 240, agree with Wohler's Table X. Rod 8 was in working order after 4 million extensions, while rod 7 under $\frac{400}{200}$ strains bore only 2,400,000 extensions. It seems unsafe to draw conclusions from these results without further tests.

The 2d division gives results which are more certain, viz.:

Axle steel { bet. + 280 and — 280 Ctr. / bet. + 480 and 0 Ctr. / bet. + 500 and + 350 Ctr. }
Strain per square inch.

The limits $\frac{+280}{-280}$ are more exact, because for $\frac{+300}{-300}$ the numbers of rotations

rose to 45 millions. Less reliable is $\frac{450}{0}$ and $\frac{800}{300}$ from Wohler's Table XII., since from 13,, millions, with respect to 12 millions, an "indefinite duration" was indicated.

The 2d division is:

For unhardened spring cast steel.	between 500 and 0	Ctr.
	between 700 and 250	Ctr.
	between 800 and 900	Ctr.
	between 900 and 600	Ctr.

Strain per square inch.

Here there is no doubt, since the 4 experiments were made with the same metal, and the bending numbers varied between 44,, and 33,, millions, which may be regarded as "unlimited duration," in view of the uniformity of the metal and the number of tests. The same may be said of the part respecting torsion.

The experiments with spring steel may be regarded as conclusive; and there remained for us only to repeat the tests on axle steel, and on metals for railway bridges and permanent way.

[The writer here regrets that his experiments are incomplete, refers to facts that caused an interruption of his tests, and expresses the hope that he will be able at some time to take them up again.]

We will now consider our subject in a more scientific and less practical point of view; with regard to the aspect and condition of the surfaces of rupture of the metals broken during our tests.

In most cases one or more spots of fine grain were observed upon the surface, showing the places where rupture first occurred. The broken surfaces of iron and steel were often marked by a dark spot; in other cases there was a smooth, fine grained spot, and in steel and bronze this was the centre of a set of radiating lines. This formed an elliptical surface, which, in Firth steel, had an oil-like smoothness and a lustre under oblique light; while the rest of the surface was rough. In Krupp's steel the elliptical surface is dull and close grained, the rest being crystalline and bright. The ellipse of phosphorbronze is yellower, and the remainder is dark brown in color.

Fracture generally began on the tension side near a corner; but sometimes near the middle.

RECENT DEVELOPMENTS IN THE TECHNOLOGY OF IRON—THE FORM OF THE FURNACE.

From "Iron."

THE question of the best form for the interior of the blast-furnace has not of late years occupied so prominent a place in metallurgical discussions as it deserves. The eager debates on the relative advantages of hot and superheated blast and monster and medium furnaces have, so far exhausted these topics, till fresh material for argument has been furnished by further experience. The contour and construction of the furnace is, however, a matter of almost equal importance as affecting the economy of manufacture, while the remarkable variation in practice on this point shows the need of doing something towards reconciling practice with theory. At the present time not only does almost every country affect a form of furnace differing in essential particulars from that improved by its neighbors, but in the same district furnaces working on the same materials frequently present widely different types. It is true that an absolute uniformity of practice is manifestly impossible of attainment, as the "lines" best suited to a particular ore and fuel would be quite inapplicable under other conditions, but, nevertheless, certain guiding principles are of general application. Cylindrical, barrel-shaped, conical, parabolic and elliptical furnaces—furnaces with high angles, furnaces with low angles and furnaces with no angles—cannot all be alike correct in principle, nor equally advantageous in practice.

The foundation of all improvements

in furnace-construction was unquestionably laid by Mr. Gibbons, who had the shrewdness to decipher the lesson "which a fiery finger had written on the walls of his furnaces." In other words, he perceived that, by adopting in the first instance the contour which experience showed would ultimately be shaped out by the action of the heated materials, whatever the original form, he should obtain at once those economical results which old furnaces generally give, but which otherwise would only be obtained after years or months of uneconomical working. And it is excellent testimony to the acuteness of this keen observer and quaint commentator, that the interpretation which he placed on the phenomena he recorded has hardly been modified in any material particular, while the best advice that could be given to furnace designers would be to study their art in the same school.

There are, however, certain preliminary considerations which should guide us in designing the best construction for a furnace, and which assist in rightly applying the information given by the eroded sections of an old furnace. Thus, the dimensions of the hearth should bear such a relation to those of the stack that smelting and reduction may proceed *pari passu*, allowance being made for the possible need of a special allowance for carburization. Then the curves or angles should be such as to offer the least possible frictional resistance to the descent of the charge—if scaffoldings and slips and their attendent evils are to be avoided. Nor should the boshes be so wide as to allow any part of the charge to lie out of the direct current of the gases. Very important is it that the gases should ascend in a regular column, spreading equally through the whole section of the stack, and not escape more rapidly at the sides than at the centre, as they very often do. Some metallurgists insist that the mixture of the elements of the charge should be promoted by the inclination of the furnace walls, while others regard the descent of the charge in parallel horizontal layers as of equal importance. The influence of the width of the furnace mouth is to be carefully considered as affecting the distribution of the charge, the escape of the gases and the reverberation of heat downwards. The mode of charging and taking off the gases, the proper thickness and best way of preserving the walls, and the most convenient mode of tapping slag and metal, are outlying branches of the subject which are well deserving of attention.

When Mr. Gibbons commenced his investigations, some forty years ago, the angle of the boshes in Staffordshire, as on the Continent, was usually laid at so small an inclination that the greatest obstruction was thereby offered to the descent of the materials into the hearth. The hearth itself was generally so narrow (2 or 3 feet square) that fusion could only proceed very slowly. The result was that a column of reduced ore would be retained in the stack long after the gases had ceased to have any further effect on it, simply because its progress towards the crucible was impeded by friction and the inadequacy of the hearth-space. It was therefore inevitable that there should be an enormous waste of fuel. Now, after some six months or a year's working, it was found that the boshes and hearth were worn away to a very great extent, so that the hearth had assumed a circular form and the angle between the boshes and the hearth was nearly obliterated, and it was only after this that the furnace began to do its best work. The enlargement of the hearth, even to the limited extent of an increase from 3 to 4 feet in diameter and increasing the elevation, and therefore the slope, of the boshes, was followed by the best results. At the present time hearths of 7 and 8 feet diameter are common, while in some instances, as at Ormesby, 10 feet has been reached. In Scotland also, as a rule, wide hearths prevail. The circular form, which the fire in any case cuts out for itself, has also been almost universally adopted. The question then arises, can hearths be too wide; or, at least, have we reached in practice the greatest profitable dimensions? Mr. Forbes is of opinion that an increase in the capacity of the hearth would, in many cases at least, be beneficial. Continental practice, however, does not favor wide hearths, and Gruner believes that Cleveland has gone too far in this direction. This metallurgist advocates the use of high and narrow hearths; and would extend his objection

to broad hearths to those of copper and lead smelting blast-furnaces, in which Mr. Forbes found wide hearths were particularly beneficial. Now, there can be no doubt that, with ordinary furnaces, a very wide hearth will sometimes cause trouble ; as, if a slip of unfused material takes place into the hearth, it is hard to get rid of it by concentrating the blast upon it. So, with very infusible ores, the concentrated heat of a narrow hearth, which also keeps the charge longer in the fusion zone above the hearth, may be very useful, unless we have a superheated blast at command. In charcoal-furnaces, also, the limit beyond which it is inexpedient to widen the hearth is soon reached. But most of the alleged difficulties with wide hearths are due to insufficient and ill-distributed blast-power. With plenty of blast—not necessarily at a great pressure—and a sufficient number of tuyeres, a wide hearth need give no trouble, while it renders it more easy to give the boshes their proper inclination. Even with refactory ores, by using a sufficiently heated blast, it is easy to keep the temperature as high as is necessary ; it is, however, for fusible mixtures that ample fusion-space is most useful. For coal-burning furnaces, as Wedding has pointed out, a wide hearth is always desirable ; hence their adoption in Scotland. The same may be said when dealing with silicious ores and hot blast if the quality of the pig is to be preserved. In the yearly increasing industry of spiegel-making, in which a high temperature is very important, the advantages of a large hearth capacity are generally admitted. It need hardly be said that the question of the proper dimensions of the hearth must, after all, always be mainly decided by the special circumstances of each furnace, such as the quality of ore and fuel available, the quality of pig it is desired to produce, and the temperature and volume of blast available. Yet, subject to these restrictions, there are not wanting indications that an increase of hearth-area might in many cases be advantageously introduced, especially if, by the use of an increased number of tuyeres, the foci of vigorous combustion which surround each tuyere are regularly distributed over the whole space, and when fusible mixtures are operated on.

We have seen that one of the effects of the shaping action of fire and friction on the interior of a furnace, as observed by Gibbons, is to plane away and round off, to a great extent, the sharp angles between the hearth and the body of the furnace. A good example of this action is shown in a section of the interior of an Austrian charcoal-furnace at Mariasgell after a campaign of several years. This furnace was giving, at the time it was blown out, results superior to any it had before attained ; and we find that it then had almost obliterated the bosh and hearth angles, and assumed a shape not unlike the continuous curve of certain Belgian and modern Staffordshire stacks. Weniger goes so far as to say that the consumption of fuel with very flat bosh-angles will be nearly double that which would be necessary with the most favorable inclination. Parry says an angle of 70 deg. is the most advantageous, while on the Continent an inclination of only 40 deg. is not uncommon. It is believed that the difficulties and unsatisfactory results which were recently encountered with certain of the monster furnaces in Cleveland were mainly due to a want of attention to this particular. The very considerable pressure exerted by the lofty columns of materials in a modern stack renders it particularly desirable to confine its thrust as far as possible to a lateral direction.

If the course of a mixed charge of fuel, flux and ore is followed from the throat of the furnace downwards, it will be seen that till it approaches the zone of incipient fusion its bulk will not be materially altered, except by the compressive action of the superincumbent mass and the gradual removal of a portion of the fuel as carbonic oxyde. This will be most conspicuously the case when the ore has been calcined, and the fuel coked, prior to its introduction. The right form for the shaft of the structure would seem therefore to be a section very gradually diminishing from the throat to the boshes, and thence rapidly contracting to the crucible. But we find that many furnaces *expand* from the top to the boshes, the enlargement being in some cases, especially in charcoal furnaces, very marked. In other cases we find cylindrical stacks, this pattern, or a near approach to it,

having found much favor in Scotland and elsewhere since its introduction fifty years ago.

It is generally assumed that the expansion of the furnace downwards is of advantage in diminishing the resistance to the descent of the materials. But both the fact and the advantage are exaggerated. The downward pressure of the column of materials is, if not greater, at least more regular in the cylindrical stack, and this is of great effect in preventing the formation of obstructions and promoting a regular descent. Moreover, a rapid descent through the stack implies a prolonged sojourn in the highly heated space about the boshes ; for it is found that the total time occupied by a charge in passing through a conical furnace is not less than that occupied in other forms of furnace. Now we have seen that it is in the comparatively cool region of the stack that reduction takes place most economically ; and it is also to be observed that it is in the lower region of the furnace that the metal takes up those bodies—such as phosphorus, sulphur and silicon—which are most deleterious to its quality. Any time, therefore, which the metal spends in the region immediately above the hearth, beyond the period absolutely necessary for carburation and preparatory fusion, is distinctly prejudicial ; while the longer time it spends in the relatively cool regions of the stack, where $CO_2 + C = {}_2CO$ reaction is mimimized, the more economical will be the result. It may be inferred, also, that in the tall furnaces now in use, carburation commences much sooner than in the old form, and that therefore the only justification for the narrow stack and wide boshes—namely, the expediency of producing a highly-carburized pig—is removed. Any considerable widening from the top downwards has also a tendency to promote accumulation of materials at the angle formed by the junction of the boshes and shaft, and hinders an equably diffused up-flow of the gases. But so great and, indeed, well-founded, is the apprehension of irregularities and scaffoldings entertained by ironmasters, that any alteration of a mode of construction which has the reputation of preventing their occurrence would be only very cautiously adopted. Yet we are not aware that either the so-called cylindrical furnaces, or those Staffordshire furnaces, which, like Gibbons' improved pattern, begin to taper downwards from a point more than halfway up the furnace, are particularly subject to this drawback.

The enlargement of the upper part of the furnace "by scooping it outwards," which Gibbons considered of the highest importance, has been advocated with great ability and particularity by Mr. Parry, of Ebbw Vale, and, at his instance, many South-Welsh furnaces have adopted the dome-shaped stack which he recommends. Though it is doubtful whether so little action takes place in the upper part of the furnace as Gibbons imagined, it is probable that, with low furnaces and friable fuel, and such ores as those of Staffordshire and South Wales, the dome shape has certain advantages which justify its adoption. A great capacity for a given height, and the accumulation of heat in the stack are perhaps its most obvious features. According to Parry's formula, the depth from the widest part to the tuyeres should not be less than the diameter at the widest part *plus* half the diameter at the tuyere-level. He also gives minute directions for the proper curve to be adopted from the top of the boshes to the mouth.

In the Rachette Furnace, which expands continuously from the hearth to the top, there is presented the most extreme contrast to the conventional type. This mode of construction presents, theoretically, certain decided advantages—the extreme division and regular distribution of the blast, among others—yet, notwithstanding the favorable accounts of its work given some years ago, it appears to have quietly dropped into the ranks of exploded ideas as regards its application in the metallurgy of iron. It remains to be seen, however, whether a modification of the principle may not still do good service ; and it is worthy of remark that in Germany, and notably in the United States, the Rachette principle, both in its integrity, and as modified by Piltz, works admirably in lead smelting. Truran, of Dowlais, proposed a mode of construction similar to that adopted by Rachette, many years ago, and pointed out that a progressive in-

crease in diameter, from the hearth upwards, would secure a more uniform descent of the charges, and, as we shall show later, both by presenting a minimum resistance to the passage of the blast, and otherwise, facilitate the operations of the furnace. It would, however, be in remote districts, where high furnaces and powerful blast apparatus are so costly as to be practically inapplicable, that this type of construction would have the most success.

An elliptical section, the application of which to blast-furnaces was patented by Algers twenty years ago, presents, in common with Rachette's oblong section, the advantage of allowing the charges to sink uniformly through the stack, and, as Dr. Percy has pointed out, renders it comparatively easy for the blast to reach the centre of the furnace however large its dimensions. A small elliptical charcoal-furnace in Massachusetts, 33 feet high, appears, according to recent accounts, to give very good results, considering its small size. On the other hand, a circular shape offers less external area for a given capacity than any other shape. That this is important, as affecting both economy of construction and loss of heat by radiation, is obvious. As the introductiton of elliptical furnaces was inaugurated with anticipations of the most glowing kind, not altogether unsupported by scientific metallurgists, it would be of interest if any our readers were to contribute any facts bearing on their subsequent history.

It may here be suggested that advantage might be taken of the forthcoming Exhibition at Philadelphia to secure much valuable information, which it would be beyond the power of any individual, or even an association, to obtain at any other time, but which, once collected, would be of the greatest service to metallurgical industry. Though some may still cling to the selfish policy of retaining and jealously guarding, as so-called *trade secrets*, all information derived from their daily technical experience, it is generally perceived that by such hoarding more is lost than gained. It is not, even now, too late for the Commissioners of England, Germany, France and Austria, in conjunction with the American Centennial authorities, to invite by circular the leading metallurgical firms of their respective countries to furnish in a specified form, such detailed particulars, illustrated as far as possible by plans, of the working of the plant and processes under their control, as they may feel disposed to give. Such information from reliable sources would at once set at rest many vexed questions, which would otherwise only be tardily solved at an enormous cost of unproductive labor and wasted material. That we ourselves have much to learn from the best Continental and American practice, is not less true than that in many points we are in advance of our neighbors. Not the least important feature in such a programme would be the collection of a series of internal sections of blast-furnaces blown out for repairs or other causes (of which there are unfortunately just now only too many). Accompanying these fire-shaped sections would be drawings of the original contour, with full details of the charges used, and the working immediately before the stoppage, and at different periods of the campaign. Such returns would form a solid basis for subsequent progress, and would materially advance that which should be the leading object of a true *world show*—the growth of technical knowledge. Failing its adoption by official representatives, we commend the idea to such bodies as the various Societies of Engineers, the American Institute of Mining Engineers, and our own Iron and Steel Institute.

An explosion lately occurred at the works of Messrs. Cammell & Co., of Sheffield. In one of their Bessemer furnaces the men were on the point of pouring molten metal into moulds when the spindle of the vessel broke and the large cauldron heaved entirely over. The metal fell into the pit, and coming in contact with some water, exploded with a terrific report. Two of the workmen had a narrow escape of their lives, having barely time to get out of the pit before the explosion occurred. The roof of the furnace was partly blown away, and a quantity of clothes belonging to melters was destroyed. The report was heard nearly a mile off.

—*The Engineer.*

NOTES ON CONCRETE.*

From "The Architect."

At one time I had under consideration the cheapest method of covering a large tank or reservoir, and it occurred to me that the construction of parallel partition walls, carrying thin concrete arches, would probably be the best solution of the question. As it would be desirable in such a case that the roof of the reservoir should be covered with about 2 feet of earth, it became a question what the minimum working thickness at the crown of such an arch should be. Apparently this was a matter of calculation, to be calculated in a few minutes, with the assistance of tables giving the ultimate strength, under compression, of concrete; or, better still, by the aid of the results of Mr. Grant's experiments on concrete blocks of various materials and various proportions of cement.

Having the opportunity I made the following few experiments, which, as such, are very incomplete, but must be, to a certain extent, interesting, as the results greatly surprised those engineers who witnessed them.

As has been said above, the breaking load of a concrete arch is readily calculated, the crushing weight of the material being given, and in a most carefully made arch—say one constructed under the immediate eye and personal superintendence of the engineer himself—the result, as calculated, might be obtained. I, however, wished to see how such a result would be affected by the superintendence not being special, the materials not specially selected, and the labor not specially skilled—in fact, to ascertain the additional factor to be applied under such circumstances.

The arches which were constructed for these experiments were four in number, all of the same dimensions exactly—namely the width was 1 foot, the span 12 feet, the rise 12 inches, the thickness at the abutments 6 inches, and at the crown 2 inches The cement was Portland, and the sand and gravel mixed as they came from the pit, and not particularly clean. The cement used was, unfortunately, not tested, but as several tests for tension were made, before and after these experiments, of cement from the same yard, it may be assumed that it was of fair average quality.

The concrete in No. 1 arch was composed of 1 part of cement to 4 parts of gravel and sand; in No. 2, 1 of cement to 6 of gravel and sand; in No. 3, 1 of cement to 7 of gravel and sand; and in No. 4, 1 of cement to 8 of gravel and sand.

The experiments were as follows:

No. 1 arch was made on August 14 and broken on December 14. The load consisted of fire-bricks carefully added (in laying each course) by equal numbers from each abutment to the crown. Care was taken, as the courses grew up, that the bricks over the crown should not touch longitudinally. A number of bricks were weighed at different times, from which the average weight was deduced. On December 15 the number of courses built up was 10, the number of bricks 556, and the load 4,059 lbs. On the 16th 4 courses were added, bringing the weight up to 5,468 lbs. On the 18th 2 courses were added; on the 21st 4 more courses, and on the 22d 4 more courses were added; and then, while more bricks were being sent for, the arch failed under 25 courses (1½ brick thick), consisting of 1,221 bricks, and weighing 9,052 lbs., or a uniformly distributed load of 754¼ lbs. per square foot of roadway. If to this be added the dead load, the breaking weight is found to be 9,521 lbs. = 4 tons 5 cwt. Assuming the curve of pressure to pass through the middle of the crown and each abutment, the horizontal thrust of the unloaded arch was 654 lbs., or 27 lbs. per square inch of section. At the time of breaking, the horizontal thrust was 17,104 lbs., or 713 lbs. per square inch of section.

Unfortunately, at the termination of the first experiments, the bricks which were loosely built up on the concrete arch until they constituted a breaking load, and to a height of 6 feet, in their fall came suddenly on arch No. 2, and fractured it.

* "Notes on Concrete, and on some Experiments with Concrete Arches." By Charles P. Cotton, Past President. Read at a meeting of Institution of Civil Engineers of Ireland.

Arch No. 3 was built on September 9, and broken on December 30. On December 28 it was loaded with 6 courses of bricks, 1½ brick thick. On the 29th 5 more courses were added, and on the 30th the arch gave way when 8 more courses had been added, making a total of 17 courses, consisting of 843 bricks, estimated at 6,070 lbs, or 506 lbs. per superficial foot of roadway. Adding to the above the dead weight of the arch, the breaking weight is found to be 6,539 lbs. When 6 courses of bricks were on, a deflection of half an inch at the crown was observed, which gradually increased to 1 inch on the 16th or last course but one.

Arch No. 4 was built on September 10, 1875, and broken on January 3, 1876. This arch, the composition of which was 1 in 8, seems to have been better put together than the last, which was 1 in 7, for it carried a heavier load before breaking. At the 8th course a slight deflection, about ⅛ inch, was observed, which on the 17th course increased to ½ inch, and on the 20th and final one to 1 inch. The way in which the arch ultimately failed took me by surprise. After the 20th course was added, it was noticed that the arch was giving way, by seeing the deflection slowly but gradually increasing, until the final rupture several minutes, probably about five minutes, afterwards. This fact and the gradual nature of the increase of deflection was plainly observed, owing to the way the bricks were built up so as to leave a clear vertical space of 2 inches over the crown. As the height of the bricks was, roughly, 4 feet 6 inches, the gradual nature of the subsidence was indicated by the slow approach of the top bricks on either side of this vertical space. The total number of bricks in the 20 courses was 911, estimated at 6,559 lbs., or a live load of 547 lbs. per square foot of roadway. If to this be added the dead weight of the arch, it amounts to a total of 7,028 lbs., the horizontal thrust from which is 12,800 lbs., or 534 lbs. per square inch of section of arch at the crown. As the weight of 2 feet of clay may be taken as 240 lbs. per superficial foot of the tank, it is clear that a very small addition to the thickness of this arch would bring it within a sufficient factor of safety.

It is a common observation to make that it is an error in design to apply concrete in the form of an arch at all, and that its true position in work is to supply, as far as possible, the place of a solid stone slab of the same size, but I do not think that its use should be so restricted. It is, of course, admitted that to employ concrete in an arched form, where full resistance to the horizontal thrust is not provided, is false design, except the arched soffit be required for other reasons, for in that case the mass of concrete can only act as a girder. As girders or bressummers, concrete beams have been employed, even to the extent, I believe, of reducing the depth of the concrete beam to one-twelfth of the span of the ope.

There are, in my opinion, many cases where concrete can be used in arches with advantage in the nature and economy of the work—in arches over windows and doors, and relieving arches over large opes, where there is a good length of wall on each side, and in small road bridges in certain places, for instance in out-of-the-way places in buildings where bricks are not to be had, and for bridges over mountain streams, where the cleanest gravel is most probably on the spot.

The resistance afforded by the abutments or walls on either side of the arches must be fully equal to that required to resist the horizontal thrust, as will generally be the case in house-building, and in bridges it must be supplied by the proper thickness of abutments. But it must not be supposed that thicker abutments are required for a concrete arch than for a stone one; the thrust of a stone arch would not be increased by the joints being petrified and making one mass with the arch-stones.

Road arches have been so constructed on the property of Mr. Richard Mahony, Dromore Castle, in the county of Kerry, under the superintendence of Mr. M'Clure, who has kindly furnished me with the particulars of these and other concrete structures on the same estate.

Mr. M'Clure writes:—"The last bridge built in 1873 is on a rapid mountain river. The abutments were built of stone, owing to the wetness of the season and the consequent danger of floods

carrying away the necessary framing for the formation of concrete piers. The arch of this bridge was completed in ten working hours by fifteen laborers and one carpenter, who had, in the same time, to wash and prepare gravel found on the spot. The dimensions of the arch are 18 feet span, 3 feet 6 inches rise, 2 feet 6 inches thick at the springing, and 1 foot 6 inches at the crown. Large stones were cast into the concrete, pressed down without any regard to regularity of position. These bridges are almost as hard as the hardest stone, and, I believe stronger than a stone bridge could be. The centres were not removed for two months"

Mr. M'Clure gives some further particulars of other concrete works on Mr. Mahony's estate as follows :

"The proportions we have used on this estate for buildings, such as farm houses, laborers' cottages, and farm-buildings, were 1 measure of Portland cement to 8 parts of well-washed sand and gravel from the bed of a river, and passed through a screen with bars 1 inch apart. The proportions used in building bridges were 1 part of Portland cement to 7 of clean river or sea gravel. Large stones are used—the roughest stones suit best—about 40 per cent. of split stone can be used safely in building concrete walls. I have used 25 per cent. in bridges. Any shape of stones can be used. In the case of buildings, the stone, or what we might call 'packing stuff,' should be placed about four inches to 6 inches apart, and should be at least 3 inches narrower than the thickness of walls, so as to form a band of concrete all around. Pressure should be applied. We have simply, in the case of house-building, packed the stuff tightly into the apparatus with wooden blocks about 2 feet long, pressing the concrete into every joint between the stones used for building the walls The dimensions for all cottage walls on this estate are 9 inches thick ; chimney walls, 18 inches ; partitions, 4 inches. I have built a large steading (which cost over £2,000) of concrete. The walls in some cases are 18 feet high, and 12 inches thick ; also a garden wall, over a quarter of a mile long, 11 feet high, and 9 inches thick ; a cistern, 5 feet high, 6 feet by 5 feet, walls 9 inches thick ; a loose horse-box, walls 14 inches thick, with a cistern over, resting on a concrete roof, capable of holding eight tons of water, and which is perfectly staunch.

The chief advantages of concrete-building are rapidity and economy. If it were more generally understood it would be largely used for buildings and bridges. I calculate at present prices (December 1874), where gravel of a suitable description can be got within two miles of the work, the cost of a cubic yard of concrete will be from 12*s.* to 15*s.*

Adie's testing machine is expensive, the cost of even the smallest being £20, which places it beyond the reach of small consumers. I believe the consumer must depend very much on the character and standing of the manufacturer to get a pure article, just as one has to depend on the character and position of a druggist to make up a medical prescription. I have found that cement kept dry for six or nine months before being used sets much more slowly than fresh cement, but forms harder concrete, almost as hard as a rock."

I have also learned that Mr. N. Jackson, C. E., who has charge of the West Riding of Cork, has built several bridges in concrete, using one part of cement, by measure, to six or even eight of clean, sharp sand and gravel, packing the piers and abutments with large stones, well rammed. Mr. Jackson finds that concrete answers remarkably well for country road bridges, especially economical in the case of skew bridges. I have also noticed, as a good instance of the application of concrete to railway works, the formation of a turn table centre-piece bed and sides, all in concrete, on a railway embankment (consequently on made ground) erected by Mr. W. A. Scott, near Mallow Station.

Lately, by permission of the engineer, the president, Mr. W. W. Willcocks, vice-presidents, R. M. Bancroft and G. I. Morrison, and a number of members of the Civil and Mechanical Engineers' Society and friends, visited the works of the London and North-Western Railway widening, Chalk Farm, the tunnel now in course of construction being the chief centre of interest.

RELATIONS OF HEAT WHEN MOIST FUEL IS USED IN GAS FURNACES.

By RICHARD AKERMAN, Stockholm School of Mines.

From "Iron."

When fuel containing water is burned, the water may simply be converted into steam, or the steam may be decomposed by contact with red-hot charcoal, hydrogen and carbonic oxide being set free. If we suppose the fuel to have a temperature of 5 deg. C., which nearly corresponds to the mean temperature of the middle part of Sweden, there are required for every weight-unit of water which is vaporized from the fuel, $95+536=631$ heat units, to which there comes to be added the heat which the watery vapor formed carries with it when it escapes from the furnace by its being heated above 100 deg. C. But as this naturally depends on the temperature at which the gases leave the furnace, it must be very different in the case of different furnaces, even if we confine ourselves, as is our intention at present, to gas re-heating furnaces.

In order to be able to estimate correctly the quantity of heat lost with the watery vapor, we ought, in the case of such furnaces, to ascertain both the temperature which the gases have when they pass out of the fire-place or generator, and that of the final products of combustion when they escape from the furnace itself. The temperature of the gases passing out of the fire-place or generator is, however, so extremely variable, according as different kinds of fuel and different constructions of generators are employed, that it may perhaps be regarded as impossible to fix upon any mean temperature which would be generally applicable with any tolerable approach to accuracy. A knowledge of this is not, however, for the object of this paper of any very great importance, on which account we shall, for the present, leave it aside, and confine ourselves to the temperature at which the products of combustion leave the furnace. This, perhaps, in our common "Koltorn" re-heating furnaces, with only a moderate extent of heating space, may be estimated at 600 deg. C., and as the specific heat of watery vapor may be taken at 0.475, the furnace, with every weight-unit of watery vapor to be found in the products of combustion, is derived not only of the 631 heat-units enumerated above, but also of $600 \times 0.475 = 284$ heat-units.

But besides this true loss of heat of about 900 heat-units for every weight-unit of water, the watery vapor occurring in the gases also occasions the very considerable inconvenience that, as the specific heat of the watery vapor is about twice as great as that of the other gases, the temperature of the products of combustion is reduced by its presence to a greater extent than would be caused merely in consequence of the loss of heat occasioned by the watery vapor. Finally, the watery vapor in a re-heating furnace is detrimental, inasmuch as it has an oxidizing action on the iron, the loss of which, by burning, is therefore increased by its presence.

The reasons why, when a fuel abounding in water is used and a very high temperature is desired, it is *necessary*, and, even when a comparatively moderate temperature is to be reached, *desirable* to employ the Siemens-Lundin principle, are accordingly evident. For in this way both the inconveniences connected with the presence of watery vapor completely disappear, inasmuch as the watery vapor is removed before the gases enter the furnance, and even the loss of heat caused by the over-heating of the watery vapor may be reduced to nothing if the generator is properly constructed; for if the gases, before they leave the generator, are made to pass through a sufficiently deep layer of fuel, their temperature need not exceed 100 deg. C., and the whole loss occasioned by the vaporizing of the water may, therefore, in this case, be limited to 631 heat-units per weight-unit of steam occurring in the gases.

In order, under such circumstances, to vaporize a weight-unit of water there is thus required, when the carbon, as is desired in a gas-generator, is burned only

to carbonic oxide, 631 : 2473=0.255 weight-unit of carbon; and the water contained in the fuel cannot, therefore, exceed 2473 : 631=3.92 times the weight of the carbon, even if dryer fuel is used for the first firing, and no loss of heat is supposed to take place through the walls of the generator. But as it is impossible to prevent loss of heat through the walls of a furnace in action, the content of water in a moist fuel intended for generating gas can scarcely exceed about 3.7 times the weight of the carbon occurring in it, and when such fuel is used, it is necessary, in addition, to mix a dryer with it in the beginning until the necessary temperature has been reached in the furnace.

If we proceed now to consider the relations of heat which exist when the water is decomposed in the fire-place by red-hot carbon to hydrogen and carbonic oxide, we find that the fire-place or generator thereby loses yet more heat, for besides the 631 heat-units consumed in producing steam, there are in this case required 29638 : 9=3293 heat units;* but it is yet of great importance in the case of gas-furnaces, especially when they are not provided with condensers on the Siemens-Lundin principle, to get the watery vapor decomposed in this way as completely as possible, for the hydrogen thus formed gives back, when burned in the re-heating furnace itself, the same quantity of heat 3293 units, and this development of heat takes place just at the place where the high temperature is desirable, while, on the contrary, the loss of heat went on in the fire-place or generator, where no very high temperature is required for any other purpose than the decomposition of the watery vapor now in question. For this a very high temperature in the generator is necessary, for if it is not high enough the watery vapor is not decomposed, wherefore, also, this relation may in this respect be said to regulate itself.

The reason of this, again, is that the decomposition in question must take place through red-hot carbon, and the thicker the layer of this which is passed through by the steam which is formed, the more complete is the conversion into carbonic oxide and hydrogen; but, inasmuch as this decomposition is attended, as we have seen, with a considerable diminution of heat, it is clear that if the layer of fuel, through which the gases formed in the generator must pass, is thick, the red-hot or active part of it must be thinner in the same proportion as the content of water in the fuel is greater, and the thinner the red-hot stratum of fuel is the less steam is decomposed in its passage through it.

If the red-hot stratum of fuel becomes too thin by the diminution of heat occasioned by a large content of water, little or no water can be decomposed in this way, but the combustion comes to go on chiefly in the way first described with a less consumption of heat in the generator; but the stratum of red-hot fuel which the gases pass through may also easily in such circumstances be so thin that none of the carbonic acid formed during the combustion is reduced to carbonic oxide. As, however, the carbonic acid is incapable of further combustion, the carbon oxidized in this way in the generator in common "Koltorn" furnaces, is of little, and in Siemens-Lundin furnaces of no use for the re-heating itself, and when the combustion goes on in this way to a considerable extent, no proper heat can be obtained in the re-heating furnace.

If we calculate how many weight-units of carbon must be burned to carbonic oxide in order to develop the quantity of heat which a weight-unit of water occurring in the fuel requires for its decomposition in the way just described, we find it to be (3293+631) : 2473=1.587 weight-unit, which corresponds to a content of chemically combined and hydroscopic water, amounting to 63 per cent. of the carbon existing in the fuel; but, in fact, if the whole content of water is to be decomposed the fuel used in a gas-furnace cannot contain nearly so much water, for even if the requisite temperature is in the beginning attained by using a drier fuel, so that it has only to be kept up afterwards with the moist fuel, there is always a deal of heat lost through the walls of the fire-place, and

* Properly speaking, there are consumed in this case only (29638—6×2473) : 9=1644 heat units, inasmuch as, for every equivalent of water decomposed by carbon, there is developed as much heat as an equivalent of carbon can give ut when burned to carbonic oxide; but this deduction ought not to be made here, for if the carbon had not been oxidized with water it would, instead, have been burned with air, and it had thus come to develop the same quantity of heat without the water.

on this account the water contained in the fuel, if it is to be completely decomposed, may certainly not exceed a little over 50, say 55, per cent. of the weight of the carbon.

Let us now see how the different sorts of fuel correspond to these requirements.

Dry and well carbonized *charcoal* may be taken as containing 82 per cent. carbon and 10 per cent. hydroscopic water, and the relation of weight between the water and carbon is then about 10 : 82, the water being 12.2 per cent. of the carbon.

Ordinary *pit coal* may perhaps be reckoned to contain 81 per cent. carbon and 9 per cent. chemically-combined water, the relation of weight between the water and the carbon in it being thus about 14 : 81, the water being 17.3 per cent. of the carbon.

Peat is more variable in its composition than coal, and it is therefore difficult to state any true average for its constituents; but if we confine ourselves to good peat, perhaps we may take it as consisting, after complete desiccation, at 110 deg. C., of about 57 per cent. carbon, and 2 per cent. hydrogen, 36 per cent. chemically-combined water, and 5 per cent. ashes. In only air-dried peat there are found from 20 to 40 and even 50 per cent. hydroscopic water, and it may therefore be taken to contain 40 per cent. carbon, 25 per cent. chemically-combined, and 30 per cent. hydroscopic water. The relation of weight between the water and carbon is thus, in thoroughly desiccated good peat, 36:57, the water being 63.1 per cent. of the weight of the carbon, and in air-dried peat 55:40, the water being 137.5 per cent. of the weight of the carbon.

Wood completely dried at 120 deg. C. contains about as much water as carbon. Air-dried wood contains besides about 20 per cent. hydroscopic water, and it may thus be taken to consist of 40 per cent. carbon, 40 per cent. chemically-combined and 20 per cent. hydroscopic water. Newly-felled and little-dried wood contains, on the contrary, 50 per cent. hydroscopic water, and upwards, and its composition may therefore be taken to be 25 per cent. carbon, 25 per cent. chemically-combined and 50 per cent. hydroscopic water. The relation of weight between water and carbon is thus, in thoroughly furnace-dried wood, 50 : 50, the water being 100 per cent. of the carbon; in thoroughly air-dried wood, 60 : 40, the water being 150 per cent. of the carbon; and in newly-felled wood, 75 : 25, the water being 300 per cent. of the carbon.

Sawdust, which has been air-dried by self-heating in a proper sawdust house, contains 27 to 30 per cent. hydroscopic water, while fresh sawdust, on the contrary, commonly contains 50 per cent. hydroscopic water; but sawdust can also be found that contains 60 per cent. The relations of weight between the water and the carbon is thus, in the three varieties above enumerated, 64 : 36, 75 : 25 and 80 : 20, the water being in the first 177 per cent., in the second 300 per cent., and in the third 400 per cent. of the weight of the carbon.

It has been pointed out that, if a fuel containing water is to be burned in such a way that its steam is completely decomposed, and carbonic oxide and hydrogen set free, the water contained must not exceed 55 per cent. of the weight of the carbon. Of the sorts of fuel above enumerated, however, charcoal and pit coal are the only ones whose content of water does not go up to this amount; but, as far as charcoal is concerned, it happens, unfortunately, too often, that it is so moist that its content of water exceeds 55 per cent. of the weight of the carbon.

As the water contained in air-dried peat amounts to 137.5 per cent., and in air-dried wood to 150 per cent. of the weight of the carbon, it is natural that neither of these kinds of fuel, and still less undried wood, which contains three times as much water as carbon, is fit for being used alone in such gas-furnaces as are not provided with condensers, but when they are used in this way, they ought to be mixed with charcoal or pit coal, as is generally done. Thoroughly desiccated wood and, still better, peat, are indeed in a much superior position in this respect, the former containing 100 and the latter about 63 of water per 100 of carbon; but even thoroughly desiccated peat of good quality does not permit the complete decomposition of the water to take place unless it is mixed with some fuel containing less water.

If the per centages of carbon and

water in different varieties of fuel are known, it is naturally easy to ascertain how much of a fuel containing little water must be added to one containing much, in order that the whole content of water may be decomposed in a proper generator. Supposing the contents of carbon and water in the different kinds of fuel to be as stated above, these proportions, *reckoned by weight*, are the following :

15.9 % charcoal with 84.1 % furnace-dried peat.
17.7 % pitcoal with 82.3 % furnace-dried peat.
51.3 % charcoal with 48.7 % furnace-dried wood.
54.4 % pitcoal with 45.6 % furnace-dried wood.
65.8 % charcoal with 34.2 % air-dried peat.
68.6 % pitcoal with 31.4 % air-dried peat.
68.9 % charcoal with 31.1 % air-dried wood.
71.7 % pitcoal with 28.3 % air-dried wood.
84.8 % charcoal with 15.2 % undried wood.
86.7 % pitcoal with 13.3 % undried wood.

These figures, however, denote merely the greatest proportion of weight in which the above-mentioned fuels, rich in water, may be mixed with fuels containing a smaller proportion, if the whole of the water is to be decomposed during combustion in a properly-constructed generator ; or, in other words, if the moist fuel is to be utilized in the most advantageous way possible without condensing the water ; but it is clear that there is nothing to prevent a smaller proportion of the moist fuel to be used than is stated above ; and it may also sometimes be advantageous, if not in a technical, at least in an economical respect, to allow the moist fuel to enter into the mixture in a somewhat greater proportion than is given above ; if, for instance, the difference of price between the moist and the dry fuels is greater than the difference of their true values as fuels. But in this case it ought to be kept in view that the moist fuel could be utilized more advantageously by being burned in a furnace on the Siemens-Lundin principle, for when the mixture of fuels contains so much water that a considerable proportion of it cannot be decomposed even when the generator is properly constructed there is good ground for placing between the generator and the furnace itself a condenser, but it is then clear that it is necessary to employ regenerators for again heating the gas. It is also to a considerable extent on this account that the consumption even of furnace-dried wood in an Ekman wood re-heating furnace is so much greater than the quantity of only air-dried wood in a Siemens-Lundin furnace, that for every centner of bar iron reheated in the former 5 cubic feet furnace dried wood are required, and in the latter 3½ to 4 cubic feet wood merely air-dried.

When the water, as in a Siemens-Lundin furnace, does not require to be decomposed, fuel can be used, as we have already pointed out, which contains so much water that it is 3.7 times the weight of the carbon, and in such a furnace accordingly it suits very well to use common fresh saw-dust, which contains about three times as much water as carbon ; but, on the other hand, it does not do, as experience also has shown, to employ alone such dark and particularly moist sawdust, with about 60 per cent. hydroscopic water as sometimes occurs, seeing it contains about four times as much water as carbon.

Such fuel as the last-mentioned cannot naturally come in question for use in the re-heating furnace, if a Lundin furnace is wanting. Even for wood, branches and peat the last-mentioned furnace is the most suitable, but if the supply of such fuel is not sufficient, it can be used in mixture with pit-coal in common "Koltorn" reheating furnaces, as, indeed, is commonly done. If the first-mentioned kinds of fuel are to be used in this way to any considerable extent, it is best, for the reasons already given, to desiccate them thoroughly in the first place, the rather as this can be done in various ways with the help of the heat often escaping otherwise unutilized from hearths and furnaces ; and that such moist fuel after thorough desiccation acquires a greatly increased value for use in the "Koltorn" furnace, is best seen from the fact that the furnace-dried "tramp" peat was considered at Bjorneborg to correspond in the "Koltorn" furnace to one and a-half times its bulk of charcoal, while the machine worked but only air-dried "tube" peat from similar mosses is in general only considered equivalent to its own bulk of charcoal, and air-dried "hand" peat is commonly reckoned to have only the value of half its bulk of charcoal, all in "Koltorn" furnaces.

As an instance of a work at which large quantites of undried poor fuel are used in the common "Koltorn" furnace,

and large quantities of peat, &c., are burned up quite unnecessarily, a place may be referred to where, for a considerable time, it was customary to consume per centner rolled bar iron not only 0.434 cubic feet coal, but also at the same 0.492 c. f. "hand" peat not properly air-dried, and 0.548 c. f. refuse wood, while at another work, in quite the same circumstances, there was employed only 0.38 to 0.40 c. f. coal without mixture with any other fuel. It seems to follow from this that the mixture of peat and wood at the first-mentioned place was not only of any use, but instead required some coal to counteract the injurious effect of the great content of water.

I hope, however, that nobody will, in consequence of this statement, understand me as seeking to oppose the employment of peat and other inferior fuel in reheating furnaces; for, on the contrary, my view is that reheating in this country (Sweden) should, for the most part, be carried on with such fuel; but we must either properly dry such fuel, if we wish to mix it in any considerable quantity with coal and employ it in reheating furnaces, or go to the expense of Lundin furnaces if it is used undried.

THE MECHANICAL THEORY OF HEAT.*

Written for VAN NOSTRAND'S MAGAZINE.

AN examination of this work satisfies us that it will not only supplement but supplant many of the more recent treatises on this subject. It is a very readable book for scientific persons, and eminently suitable as a text book for advanced students. It has the merit of analytical treatment of the subject in the most complete and satisfactory manner. The style of the author is so happy and engaging that the reader is unconsciously interested, in what, in ordinary words on this subject, are quite dry and uninteresting details. The first part gives the reader a condensed and yet complete synopsis of the history of the investigations in heat, by Huggens, Fresnel, Rumford, Sadi, Carnot, Mayer, Joule, and others, so admirably arranged in matter and composition as to give the reader a sincere pleasure in its perusal. Then follows a clear deduction of the fundamental laws and principles of Dynamics, based upon the General Law of Energy, and the Mechanical Theory of Heat is shown to depend upon this law, and to be indeed but the expression of it so far as it relates to this most interesting branch of Molecular Physics. The author has attempted and indeed accomplished in a most satisfactory manner, in the domain of Heat what we hope to see done in the near future in that of Magnetism and Electricity.

Following the demonstration of the general dynamic laws the reader is at once led to the study of temperatures, quantities and measure of Heat, thermodynamic functions and their discussion, the theoretical determination of Joule's coefficient Absolute Temperatures, and other kindred branches of the subject.

The fundamental laws of the more permanent gases, deduced by experiment, are compared with the theoretical deductions, and are carefully examined in detail; and, by a very simple process, the differences are shown to fall within the limits of probable error of observation, or to be so small as to be neglected.

Clear discussions of the methods of Elimination of Internal Energy, and its application to Steam and air Engines of the Cycles of Carnot—of air engines in general and in particular—of Isodiabatic and Adiabatic Curves, and of lines of transformation, followed by an accurate comparison of the efficiency of Air and Steam Engines, give to the attentive student a most thorough grasp of this ordinarily involved and intricate subject. This is suplemented by a masterly analysis of the most recent investigations made by Rankine, Sir W. Thompson, and other able scientific men who are to-day standard authorities in these matters.

The author has thus happily grouped together in a compact form, the elementary principles of his subject, and deserves the gratitude of every lover of clear

* McCulloch on the Mechanical Theory of Heat and the Steam Engine. In press by D. Van Nostrand.

statement and accurate analysis, no less for these qualities than for the happy faculty he has displayed of creating in his readers an intense and well sustained interest from the first to the last of this book.

As a text book it is admirably adapted to those students who have mastered the Calculus; for although it is a condensed treatise, the discussions are remarkably clear and complete, and so well arranged and connected that there is an orderly progression from the fundamental principles of the science to the most recent developments of the present time.

We welcome this book as being the embodiment of all that such a book should be, and the forerunner of a class of standard works on science of which the scientific men of our country may well be proud.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—TESTS OF AMERICAN IRON AND STEEL.—During the past year, the United States Board appointed to test Iron, Steel and other Metals, under authority of an Act of Congress procured by a committee of the Society, has been organized, has prepared the plans of investigations to be adopted, and has appointed its committees on the several subjects to be studied.

The general plan is announced, and is to be a thoroughly scientific and systematic exploration of the field assigned to the Board. Materials are not only to be tested and the results stated as those derived from the examination of a metal of a conventional denomination, but the test-piece, in each case, will usually be examined to determine how far peculiar qualities are attributable to peculiarities of chemical composition and of physicial structure.

Circulars have been issued by the committees of the Board requesting men of science, engineers and manufacturers of metals to communicate to the Board all information which they may be able to submit relative to the subjects under investigation. A considerable amount of valuable material has thus been obtained. Even foreign correspondents of the Board exhibit great interest in the matter, and some of the most useful papers received by the Secretary were sent in by Mr. Forrest, the Secretary of the British Institution of Civil Engineers, Mon. Tresca, of the French Conservatoire des Arts et Metiers and other well-known European authorities.

A chemical laboratory has been established at Watertown Arsenal and the chemist to the Board, Mr. Andrew A. Blair, formerly of St. Louis, has already done a large amount of work upon irons, steels and other metals and alloys, and the specimens thus examined as to composition are subjected to the several kinds of mechanical stress to discover the effect of composition in determining resistances for distortion and rupture.

A series of steels is in preparation under the direction of the Committee on Chemical Research, in which other elements being retained constant in amount, the carbon varies regularly from 0 to 2 per cent.; another series, with carbon uniform, has silicon in varying proportions; another set varies in phosphorus, still another in sulphur, and another series is variable in manganese. In each series, one element varies between wide limits, while the other elements are all retained as uniform as possible. The work of the melter is checked by analysis, and the specimens are then tested mechanically. This investigation, greatly as it has been needed, has never before been even attempted. It is considered by the members of the Board as likely to prove the most valuable research ever made in this direction, and the only one in which the chemist and the engineer have ever systematically joined forces in making such an exhaustive and scientific investigation.

The Committee on Abrasion and Wear is engaged in collating information relating to this subject, and is making experiments at the Stevens Institute of Technology on the abrasion and wear of the metals, and on the effect of lubrication in reducing it. The Chairman is fitting up machinery and apparatus for use in further investigation. A considerable amount of work has been done.

The Committee on Armor Plate is engaged in collating information from domestic and foreign sources that may be valuable in determining the qualities requisite in armor plate, and how those qualities are to be secured. The records of the Army and Navy Departments and of the British Admiralty are considered to be the most promising mines of information to be worked by this committee.

The Committee on Chemical Research has charge of the chemical work referred to.

The Committee on Chains and Wire Rope is endeavoring to determine the character of metal best adapted to making chain and rope, and the proper form and proportions of link, and is working up the data which have long been collecting at the Navy Departments. The later experiments of Com. Beardslee are extensive in range, and that officer is collating and arranging the records for the use of the Board. Further experiment will fill up any hiatus that may be detected. The Navy Yard at Washington, where this work is going on, affords peculiar facilities not only for testing, but for making chain cable of any desired size, form of link or quality of metal.

Work already done there by the Chairman of this committee has revealed serious defects in accepted tables of sizes and strength, and has indicated the rate of variation of strength with variation of size of bar, and permitted the formation of a new and trustworthy table.

The Committee on the Corrosion of Metals is investigating the conditions affecting the corrosion of metals in use. Some information has been collected, some chemical work has been done, and much more work is projected for the ensuing year.

The Committee on the Effects of Temperature has planned an extended investigation of this subject and is gathering information from various sources. The research will be commenced by the Chairman during the coming year, if the Board is sustained in its work. The Chairman has already collated all published information accessible in periodical literature, has made some preliminary experiments, and is receiving some information from various directions.

The Committee on Girders and Columns has a plan of operations which includes elaborate investigations of the strength of materials in columns and girders of various forms and proportions. This is the most formidable and expensive of the researches to be undertaken by the Board, and the power and accuracy of the 400 tons testing machine will be fully taxed in this work. The committee is receiving the cooperation and active aid of some of the largest manufacturers of beams and girders in the country. The results of experiments already made have been communicated to the committee by the engineers of railroads and of mills, and in other cases important and costly experiments have been undertaken by private incorporated companies (the Board has been invited to be present and to assist in the work if it should seem desirable); these results are to be given the Board, such sizes and proportions as the Board may desire to test are to be made and all necessary labor furnished without any expense to the government. Bridge builders, civil and mechanical engineers and architects are corresponding with the Board on this subject, and the greatest interest and a most gratifying public spirit are said by the members to be exhibited on all sides.

The Committee on Malleable Iron has collated a large mass of valuable information, and the records of a great number of experiments, and, among other important matter, has obtained an extensive collection of experimental determinations of the effect of time upon the elevation of the elastic limit by strain, during periods varying from a few seconds up to a year. The variation of quality due to differences of size and form of section of the bar and the modification of strength, ductility and resilience are under investigation. The Chairman of this committee is also determining the influence of proportions of test-pieces upon their ultimate resistances.

The Committee on Cast Iron is pursuing a course similar to that of the Committee on Malleable Iron with similarly promising results.

The Committee on Metallic Alloys has made an investigation of the strength and other properties of bronzes, which may be taken as typical of the kind of work to be done by the Board.

Several series of copper-tin alloys were prepared, varying in some cases by regular percentages, and in others by chemical equivalents, and were cast in bars of 1 inch square section and about 20 inches long. Their temperatures of fusion were taken at casting, and some were cast in sand, and others in an iron ingot mould. The weighing was carefully done in a Coast Survey balance, in the Physical Laboratory of the Stevens Institute of Technology. A set was reserved for the determination of the coefficient of expansion, by Dr. Mayer. The others were broken by transverse stress, one set by dead loads, and others in the transverse testing machine of the Mechanical Laboratory, and deflections and tests were recorded to the fourth place of decimals, in inches, and also in meters with equal precision. The logs were made up, and the results were also laid off graphically. The curves revealed some peculiar and important facts. The fractures were photographed and, were peculiar, were reported upon by Prof. Leeds, the chemist and mineralogist of the Institute. From the data obtained, the co-efficients of elasticity were calculated and recorded

Complete sets were next broken by tension, and the results recorded and worked up as with the transverse tests, and the logs and curves compared, and a series of compression specimens were made up as companion test-pieces.

The full series was finally tested in the autographic recording machine and from the strain diagrams, their strength, elasticity, ductility, resilience and homogeneousness were deduced, and the law of variation worked up graphically. The effect of strain in elevating the elastic limit was observed.

All specimens were examined by the chemist, and a comparison made between the proportions by mixture and composition in the bar which exhibit the loss of metal, and to some extent, change of physical character, produced by melting and casting. Some curious and interesting scientific facts are revealed by the research, and a new mineral consisting of stannic acid, with a trace of copper in magnificent needle-shaped crystals was produced in some cases, which has been subjected to examination and analysis by Prof. Leeds.

A determination of specific gravities of the metals as purchased, as cast and as compressed mechanically and in mass and in a state of fine division, concludes this research.

A similar research is in progress, under the direction of this committee, by Prof. Thurston, its Chairman, which is intended, also, to be as complete and accurate as the resources at command will permit.

Before entering upon this work, the Chairman collated all published material bearing on the subject, and a preliminary report of about one hundred pages embodies the most important facts previously determined, and contains the bibliography of this subject of copper-tin alloys. This work was supplemented by making graphical records of the experimental work of Mallet, Mathiessen, Calvert, Johnson and others on the conductivity for heat and electricity, the specific gravity and other properties of copper-tin alloys, as had been examined by them. It was the intention to profit by facts already acquired by acknowledged authorities, to complement them by the new investigations, and to avoid useless repetition of work involving serious expenditure of time.

This paper is itself regarded as exceedingly valuable, and particularly to the mechanical

engineer, as it is the first time that these earlier researches have ever been collected and put in an accessible and compact form.

A similar preliminary research is made to preface the examination of the copper-zinc alloys, and the same plan will be pursued throughout.

The Committee on Orthogonal Strains is planning a series of experiments to determine the laws of the resistance of materials under simultaneous stresses acting in rectangular directions, as in the case of a rod subjected to torsional or shearing simultaneously with tensile or compressive stress. The subject has been entirely unstudied up to the present time.

The Committee on Physical Phenomena is preparing to seek for the phenomena induced by stress in the various physical models of energy, as the development of magnetic, electric and thermal actions. The fact of the development of heat and electricity has long been known, but no systematic or scientific investigation has ever been made in this direction.

The Committee on Steel produced by Modern Processes is working with the Committee on Chemical Research. It is collecting also the vast mass of material available and will endeavor to make a report which shall be of great and permanent value.

The Committee on Re-heating and Re-rolling is to test iron &c., in the several stages of manufacture, refined and unrefined, and to observe the effects of successive re-heats, of reworking and rolling, to determine, if possible, what amount of work is demanded by different irons, and what are the temperatures which will practically give the best results.

The Committee on Steel for Tools is making an extended series of experiments at the Washington Navy Yard to determine the value of various steels for tools. A large collection of steels is made ; their composition is determined, and they are there carefully tested by setting them at work—turning, planing, boring and chiseling—and their behavior and their composition being thus ascertained it will probably be easy to learn the chemical and physical characteristics of the best tools. The names of makers are of no importance in this investigation, and are not to be reported. The Board, in all its work, will avoid reference to makers of material in any way that may injure any manufacturer directly or indirectly. Scientific knowledge of directly practical value and engineering facts and figures, solely are sought.

The testing machine ordered by the Board is well under way, and it is expected will be soon completed, when the Board will be prepared to undertake the heavier and more accurate work laid out by its committees. The machine was designed by Albert H. Emery, and has an attachment designed by Charles E. Emery, for obtaining an autographic strain diagram. Its capacity is 800,000 pounds, in both tension and compression. The committee of the Board appointed to examine and report upon it, considered it an extremely accurate and effective form of machine, and far superior to any other then known to its members.

The building, the foundation, and the accessory machinery are all in hands, under the charge of the several committees of the Board entrusted with these matters, and will be ready for the machine before its completion.

The Board is not prepared to make a report, as all the work is in progress and none yet completed. If desired, the members state their willingness to present to the appointing power, and to Congress, a statement of their status. They expect to be able economically, to use $50,000 during the year 1876–7.

At a meeting of the Board of Direction of this Society, held February 9th, 1876, the plans and work of the Board were considered and the followiing adopted :

Whereas ; the Board of Direction, of the American Society of Civil Engineers has informed itself as to the work performed, in hand, and proposed by the United States Board appointed to test Iron, Steel and other Metals, and has been led by such information to the following conclusions :

1st. That the 400-tons testing machine ordered by the Board and now nearly three-fourths completed, has been built under extraordinary close inspection, and is remarkably well built, both as to material and workmanship.

2d. That even without the use of this testing machine, the Board has accomplished a large amount of useful work, viz. :—The establishment of a chemical laboratory and the engagement of an experienced chemist ; the arrangement of a comprehensive series of comparative chemical and physical tests and the already completed analyses and preparation of specimens for test from a large number of irons and steels containing different hardening and toughening ingredients ; also the preparation of a complete series of specimens of the various bronzes, a number of which has been submitted to analysis and to a part of the necessary mechanical tests—the results of which must be that all these materials can be more closely adapted to the large variety of stresses they will have to bear in use, thus avoiding the present excess of material and cheapening structures and machinery as well as increasing their safety, and also making the production of materials a matter of scientific synthesis rather than a trade secret ; that the board has collected and classified a mass of information about the useful work done elsewhere in testing metals ; that it has commenced a comprehensive series of experiments on tool-steels and arranged for the construction of some large iron and steel columns and girders for tests ; that it has availed itself of the results of a series of tests of wrought iron, especially in the form of chain cables, previously undertaken by one of its members for the Navy department, and has commenced more comprehensively carrying out these experiments and completing their usefulness by means of chemical analysis ; and that it has prepared as far as its means will allow, to undertake tests in other departments.

3d. That the character of the experiments undertaken and proposed by the Board is judicious and comprehensive, and if carried out

on these plans, will be of great value to engineers, constructors, producers of constructive materials and the public at large.

4th That the information derived from these experiments should be of the first and greatest value to the Government directly, in its own constructions of vessels, engines, boilers, cannon, armor plates, light-houses, etc.

5th. That in order to carry out to comprehensively useful results, the series of tests already undertaken, the Board will require a considerable sum of money, chiefly to increase its chemical department and to pay for material to be tested, and for the manufacture of such new shapes and compounds as current tests may prove it desirable to experiment upon.

Therefore it is Resolved—That the Board of Direction of the American Society of Civil Engineers respectfully petitions the honorable Senate and House of Representatives in Congress assembled, to grant to the United States Board appointed to test iron, steel and other metals, the sum of fifty thousand dollars, to be expended in carrying out the investigations of the Board, as explained in its various printed circulars.

IRON AND STEEL NOTES.

THE IRON INDUSTRY.—The American Iron and Steel Association has just published a directory of furnaces, rolling mills, steel works, forges and bloomeries in every State of the Union. The following is the summary of the number and capacity of the furnace and rolling mills in the United States:

	Tons of 2240 lbs.
Whole number of completed blast furnaces January 1, 1876.....	713
Annual capacity of all the furnaces.....	4,856,810 tons.
Whole number of rolling mills, January 1, 1876.....	332
Whole number of single puddling furnaces (each double furnace counting as two single ones).....	4,475
Total annual capacity of all rolling mills in finished iron.....	3,740,860 tons.
Annual capacity of all the rail mills in heavy rails.....	1,732,410 tons.
Number of Bessemer steel works January 1, 1876.....	11
Annual capacity in ingots.. ..	450,000 tons.
Number of Bessemer converters	24
Number of open hearth steel works January 1, 1876.....	16
Number of open hearth furnaces	22
Annual capacity in ingots.....	41,000 tons.
Number of crucible and other steel works January 1, 1876..	39
Annual capacity of merchantable steel.....	97,550 tons.
Of which there are of crucible steel.....	41,000 tons.
Number of catalan forges making blooms direct from the ores January 1, 1876.....	39
Annual capacity of blooms and billets.....	53,080 tons.
Number of bloomeries January 1, 1876, making blooms from pig iron	59
Annual capacity in blooms....	53,750 tons.

FRENCH TREATMENT OF SLAG.—A new French process for the treatment of slag is claimed to realize the most profitable results yet obtained in the utilization of that hitherto worthless material, notwithstanding the various successful efforts, which, within a comparatively recent period, have been put forth in this direction.

The method in question, as described, is not to employ the slag directly, to form artificial stone or pressed bricks, but to reduce it to a fine state of division, in which it becomes capable of a great variety of uses in addition to those for which it was originally supposed to be adapted.

The channel through which the molten slag flows from the furnace is made, in this arrangement, to terminate in a running stream of water leading into a pit or excavation. On striking the water, the lava stream of slag is blown and broken into a sort of fine, porous gravel, which the flow of the water then bears along into the pit. Meanwhile, the iron grains contained in the slag, which previously were separated by crushing, are now sorted out by this water process, sinking to the bottom by their weight, instead of being carried on with the rest. The slag sand accumulating in the pit is charged thence into wagons or railway cars by means of an endless chain and buckets driven by an engine run by hot gases from the furnace.

Thus treated, the artificial sand or granulated slag is said to be not merely easier and cheaper to get rid of, but applicable to a number of valuable uses. One of these is for casting sand, pigs made in such a bed coming out exceedingly handsome and bright. For this purpose the material is now very largely used in some parts of France, Belgium and Prussia. The next step was a natural outgrowth of the last, namely, to use the finer portions, separated by sifting, to sand the moulds for fine castings; thus employed it is found cleaner and better than common sand, and the castings are improved. Another use to which this artificial or metallic gravel is put is that for ballasting railroad tracks, for which it is very serviceable.

Being also very porous, packing well, and holding but little wet, this slag sand forms a valuable concrete like mortar, and not only this, but is capable of being used for cement. This is regarded, in fact, as its most important specialty, it being found that first-class cement can be thus obtained from almost any slag at a very small cost; a large manufactory having been erected for this purpose, after long and full experiment at one of the leading German works.—*Iron Age.*

RAILWAY NOTES.

CREEPING OF RAILS.—The "creeping" of railroad rails has attracted some attention of late, and, while we do not attempt to explain

it, we offer a point on the fact that on lines running north and south the western rail "creeps" faster than the eastern rail,—that is, this strange movement of the rail toward the south is more marked in one rail than in the other on the same track. Furthermore, it has been noticed that on such a line the eastern rails wear out the faster. Both of these points, we think, can be explained by the motion of the earth as it turns from the west towards the east. Everything that has free motion is dragged after the whirling globe; every wind that blows and every tide that moves feels the influence, and our train going north or south is pulled over toward the east, and naturally presses the eastern rail most heavily. The western rail, being relieved of its share of weight, "creeps" more freely and quickly. It is also noticed that the wheels that run on the eastern rail wear out the first, and we can but think that this earth motion is the true cause. The practical side of this is that the eastern wheel and rails should be stronger.

STEEL GRADIENT LOCOMOTIVES.—The New Zealand railways being, as is pretty well well known, laid over hills with some rather severe inclines, have to be worked on a somewhat similar system to that employed on the Mont Cenis railway. The gauge is 3 feet 6 inches, and there is a central rail at an elevation of 6½ inches above the level of the two outer ones constituting Mr. Fell's system. The Government has ordered four locomotives of an improved type, which are now being made from their own designs by The Avonside Engine Company (Limited), of Bristol. So much thought has been expended on these engines, and so many special contrivances introduced, producing in the end so splendid a result, that Mr. John C. Wilson, the engineering and general manager of the Avonside Company, has every reason to congratulate himself on his work. On Saturday last one of the locomotives was tried on a short temporary line of railway, laid down in the yard of the Bristol Wagon Works, by the kind permission of Mr. Fry, the managing director. Here tests of every imaginable description were applied, and the results were uniformly satisfactory. The line was too short, however, to make any experiments such as those tried by the Railway Accident Commission, at Newark, much to the regret of the spectators, as the special brake answered so admirably that it would have been interesting to learn exactly how short the distance really was in which the engine was stopped against full steam.

The length over all of the locomotive is 21 feet 6 inches, and its width 9 feet 3 inches. It is driven by two pairs of wheels, coupled, of 2 feet 8 inches diameter, on which about 28 tons of the weight rest, and the trailing wheels are 2 feet 6 inches diameter, carrying about 6 tons, the total weight of the engine being about 34 tons. The trailing wheels are fitted with the "radial axle boxes," patented by Mr. H. W. Widmark, of Bristol. These are intended to provide for the easy turning of curves, and are adapted in this instance to curves of the short radius of 300 feet. They are provided with cylindrical guides, and with planes set at an angle to the central line of the axle, while at the top are inclined planes calculated to give much elasticity. We understand that these axle boxes have given good results in working, and on Saturday it was evident that a considerable amount of play was given as the engine rounded the curves of the experimental line. The boiler is arranged for a variation in water level corresponding to an inclination of 1 foot in 15, this being the steepest slope on the New Zealand lines. It has 170 tubes of 1¾ inches diameter and pitch of 2 $\frac{7}{16}$ inches. The grate area is 13 square feet, and the heating surface of the fire-box 74 square feet, that of the tubes being 783 square feet, affording a total of 857 square feet. The tanks hold 614 gallons, and the coal-box has a capacity of 36 cubic feet. The driving engine for the vertical or ordinary wheels consists of a couple of cylinders of 14-inch diameter and 16-inch stroke, while a smaller pair of cylinders of 12-inch diameter and 14-inch stroke work the four horizontal wheels of 22¼-inch diameter which grip the central rail. These may be called the outer and inner engines respectively, and the gearing is so arranged that either may be worked separately, or they may be worked simultaneously, either in harmony or antagonism. Two pairs of volute springs keep the horizontal wheels apart, while a couple of powerful crescent spring exert a pressure of 28 tons to bring them together. This is, of course, the useful pressure upon the centre rail, while a corresponding amount is exerted upon the driving wheels, thus giving the large quantity of 56 tons useful adhesion for a 34-ton locomotive. The valve motion for the inside (Fell) engine is an adaptation of Walschart's system. The brakes are double—the ordinary lever-brake being fitted to the driving wheels, whilst a highly efficient brake is fitted to the central rail, gripping it like a pair of nutcrackers. Another noteworthy minor feature is a peculiar link motion in the coupling, which is Stradal's and is so arranged that even with the utmost lateral motion a pull away takes effect on the central line of the vehicle.

These locomotives are intended to work in pairs, being coupled end to end, so that the drivers work together, with one stoker between them, and they are calculated to draw 100 tons up an incline of 1 in 15 at a rate of five miles an hour. The following are the principal results of Saturday's trial.

(1) Either engine alone was sufficient to drive the locomotive, and a *fortiori* both together drove her admirably.

(2) The engines being set to work against each other, *i. e.*, the outer ones being driven forward and the inner ones reversed—the latter, gripping the central rail, proved to be more powerful.

(3) Both engines being at work, the brake power was sufficient to stop the locomotive—steam being full on at 125 lb.—within three or four times her own length.

ENGINEERING STRUCTURES.

THE IMPROVEMENT OF THE DANUBE.—At a meeting of the Edinburgh Royal Society,

held lately, Sir Wm. Thomson presiding, Professor George Forbes read a paper, principally founded on theory and intended to show a connection between cohesion, elasticity, dilatation and temperature. Mr. Stevenson followed with a notice of the completion of works designed by Sir Charles Hartley, for improving the Danube. He reminded the meeting that in 1854 a commission of eight delegates, representing the different powers in Europe, was appointed to adopt means to improve the Danube, so as to make it accessible to the shipping of all nations. The Danube entered the Black Sea by three mouths, and it involved a good deal of discussion as to which of these should be chosen as most suitable for their operations. Soulina, as the mouth discharging the least water, was not apparently the one which would have been selected, but the particular circumstances of the Danube led them ultimately to this decision. The discharge of alluvial matter from the three mouths was most enormous, amounting to 900,000 tons every twenty-four hours. Soulina discharged only 70 000 tons, but even this deposit embraced a very difficult engineering problem. In dealing with it Sir Charles Hartley advised the commission, and the advice was followed, to construct piers on both sides, so that the water might be narrowed and the deposit carried into the deep water of the Black Sea. The works had been executed, and the practical result of it had been that, while in 1854 the natural depth at the Soulina mouth was 11 ft., the depth of 20 ft. was now maintained. The piers were 8,000 feet in length, and had cost £180,000. As regarded navigating, there had been an increase of shipping of 16 per cent. on the number of vessels, and an increase of tonnage of 50 per cent The number of shipwrecks had also been greatly diminished.

A Proposed Bridge Across the Thames.—Lately Mr. Frederic Barnett laid before the Society of Arts a proposition for a new bridge, for providing for the traffic across the Thames below London Bridge. Mr. Barnett said: "My patent bridge has but one approach from each shore. When these approaches have extended into the river about one-third its width, the roadway splits into two roads, each the same width as the approaches, by easy inclined angles, outwardly extending till they meet midway, thus forming a sort of angular oval or loop in the largest diameter. I have on each side two openings, practically covered and united by platforms, turning on their centres, each opening or closing by one operation. These openings permit the entrance on the port side of the largest ships that come up the Thames; there is also a sufficient width allowed for the length for the ships within the loop. From the central piers on which the turntables work, there is extended a platform uniting the two extremes, so that this platform lies with the axis of the river, dividing the loop into halves, furnishing the means of mooring the ship a few minutes alongside by mooring blocks. There are two other platforms running parallel to the chief platform, which keep the ships straight on their road. The vessels return on the opposite, still going port; thus all risk or collision is avoided. The platform will have narrow lighters, rising and falling with the tide, thus protecting both piers and vessels from injury. As soon as a vessel is about to enter the loop, the roadway on the side by which it is to enter is closed, and the vehicular and general traffic, by closing the gates (when the roads divide), is diverted to the opposite side; then immediately the turntable-bridge is opened, and the vessel enters the loop, so that when it is fairly in, the bridge is closed behind it, and, as before described, the traffic is diverted on the road behind the ship, and the opposite turntable-bridge is opened, suffering the ship to pass out on its way."

Such a structure as that proposed would block up the river and prove an enormous nuisance. Further consideration of it would seem to be useless.

ORDNANCE AND NAVAL.

Facts About the Big Guns.—The following statement of the costs and sizes of the "big guns" of Europe will be found of interest: The 81 ton gun has cost $75,000, and the price named for the "Newcastle infants," of 100 tons for the Italian navy is, $120,000 each. We have not seen it stated what the Krupp monster is to cost, but it will probably be $150,000 or more. The testing of these guns, to say nothing of their use in actual service, adds not a little to this enormous expenditure. Every time the 81-ton piece is fired it blows $125 into the air, 240 pounds of powder and a projectile of 1260 pounds being the charge in the first trials. In some of these rounds, 250 pounds of powder and a 1465 pound shot were used. It is now proposed to increase the bore of the gun from 15½ inches to 16 inches, after which operation the charge will be proportionately augmented. The Italian guns are to fire projectiles of 1860 pounds each, while the Krupp cannon will send a ball of 1040 kilogrammes, or about 2300 pounds, through the air; how much powder is to be used in doing it we are unable to say. One gets, however, a new idea of the power of gunpowder when he learns that a few hundred pounds of it can propel a missile of more than a ton's weight over a distance of several miles. In the case of the 81-ton guns the shot of 1260 pounds left the muzzle with a velocity of 1400 feet a second, and a momentum that would carry it through 20 inches of iron plating at a range of half a mile. The Duilius, for whose armament the four 100 ton Armstrong guns are intended, is described as being the most powerful iron plated frigate ever yet devised. She is to be armored with plates 19 inches in thickness, and moved by engines of 7000 horse-power.—*Engineer.*

BOOK NOTICES.

A Practical Treatise on Roads, Streets and Pavements. By Maj.-Gen. Q. A. Gillmore, A. M. New York: D. Van Nostrand. Price $2.00.

We gave considerable space last month to a

review of this work, containing some important extracts. The entire scope of the work will be better understood by the following extract from the table of contents :

Chapter 1. Location and Grades of Country Roads ; 2. Earthwork, Drainage and Transverse Form of Country Roads ; 3. Road Coverings ; 4. Maintenance and Repairs of Roads; 5. Streets and Street Pavements ; 6. Sidewalks and Footpaths ; and 7. Tramways and Street Railways.

Illustrations accompany every chapter.

JOURNAL OF THE ROYAL UNITED SERVICE INSTITUTION. Nos. 80, 81, 82. London. For sale by D. Van Nostrand.

Every issue of this valuable journal contains something nearly indispensable to the engineering profession. In the above numbers we find Comparative Merits of Simple and Compound Engines ; The New Works for the Defence of Paris ; The Unsurveyed World; Harbor Defence ; Signaling by Explosions ; The Macomber Gun; Military and Refuge Harbors.

Maps and other illustrations are abundant.

MATHEMATICAL TABLES. New Edition. London and Edinburgh : W. & R. Chambers. For sale by D. Van Nostrand. Price $1.75.

This is a well printed volume of convenient size, containing, besides the common mathematical tables, a useful compend of the various nautical tables, together with tables for conversion of thermometric scales and for binomial co-efficients used in interpolation.

HYDRAULIC EXPERIMENTS AT ROORKEE. By Capt. ALLAN CUNNINGHAM, R. E. Roorkee : Thomason College Press.

This book is an extra number of the series of " Professional Papers on Indian Engineering."

The experiments referred to were performed in the Ganges Canal in the neighborhood of Roorkee. The conditions were unusually favorable for a comparison of methods : The canal here presents within a reach of six miles three sorts of channel ; 1st, A Trapezoidal Channel in Earth, three miles long, and 150 feet average width ; 2d, A Trapezoidal Channel in masonry, two miles long and 150 feet wide ; 3d, Rectangular Twin Channels, 932 feet long, and each 85 feet wide; then a fourth section of half a mile length follows of the same description as No. 2.

The different methods known to engineers for measuring the velocities, and deducing therefrom the actual discharge of streams, were evidently tried with scrupulous care, and the results are carefully recorded in the book before us.

The value to the practical engineer of such a record of experiments is not easily over estimated. In this branch of engineering particularly are we in need of carefully prepared data to enable us to reconcile conflicting professional opinions, or else to aid us in choosing between them.

We have no space here for such extracts as would do justice to the writer. In our next issue, however, we will give at least a summary of the results obtained.

GUIDE POUR L'ANALYSE DE L'EAU. Par Dr. G E. REICHARDT. Paris : Reinwald et Cie. For sale by D. Van Nostrand. Price $1.80.

A pamphlet only of 100 pages, but treating the subject systematically and thoroughly.

The chemical processes are fully described both for qualitative and quantitative examinations. The microscopic analysis receives a fair share of attention, and is illustrated with excellent woodcuts of the crystaline deposits.

A MANUAL OF QUALITATIVE CHEMICAL ANALYSIS. By WM. DITTMAR. Edinburgh: Edmondston & Douglas. For sale by D. Van Nostrand. Price $2.50.

This is a well printed and well arranged book for students. There is no pretension on the part of the author that anything particularly new is presented in the way of methods or classification, which is much in its favor. The book, however, is certainly up with the times, and more than the usual amount of space is devoted to the rationale of processes.

A GUIDE TO THE MICROSCOPICAL EXAMINATION OF DRINKING WATER. By J. D. MACDONALD, M. D., F. R. S. London : J. & A. Churchill. For sale by D. Van Nostrand. Price $3.50.

The text of this work is very brief, and is but little else than a zoological table of classification, but there are twenty-four full page plates of representations of living things as they appear under the microscope.

If it is proven that these are the regular inhabitants of ordinary drinking water, the temperance reformers will not find an ally in this author.

AN ELEMENARY TREATISE ON KINEMATICS AND KINETICS. By E. J. GROSS, M. A. London, Oxford and Cambridge : Rivingtons. For sale by D. Van Nostrand. Price $2.75.

This a brief treatise on elementary mechanics, with numerous examples for practice. It is designed for students who are not proficient in Analytical Geometry or the Calculus.

For students who are reviewing and preparing for college examinations, the work will prove of great convenience by reason of the abundance of examples requiring application of important principles. A key to all the solutions is given in the appendix.

EXERCISES IN ELECTRICAL AND MAGNETIC MEASUREMENT. By R. E. DAY, M. A. London : Longmans, Green & Co. For sale by D. Van Nostrand. Price $1.25.

Nothing in the way of preparatory explanation is afforded in this book. It is a collection of examples for the student with answers in the appendix.

No better way could be devised for attaining familiarity with the practical applications of electrical science than practising upon these examples. But it is necessary to warn the student that he is not prepared for the work when he has simply accomplished the course in science which is at present prescribed in the schools. Some familiarity with the science of the telegrapher and the physicist as set forth in later practical treatises is necessary for a beginning with these useful exercises.

PHYSICAL GEOGRAPHY OR THE TERRAQUEOUS GLOBE AND ITS PHENOMENA. By WM. DESBOROUGH COOLEY. London: Derlau & Co. For sale by Van Nostrand. Price $10.50.

An octavo volume illustrated with 125 wood engravings and 12 maps.

All the topics usually presented under this comprehensive title are presented in logical order, and with proper regard to space due to each subject. In such a cursory glance as we were enabled to give the work, we noted a gratifying absence of statistical tables, which lend to some of the late works on Physical Geography an uninviting look to say the least. We, moreover, found it impossible to turn away from the book without reading thoroughly all the author presented on the subject of Tidal Phenomena and on Glaciers and the Theories of the Glacial Epoch.

We can therefore heartily recommend so much as valuable, and we presume the entire treatise is also.

LECTURES ON SOME RECENT ADVANCES IN PHYSICAL SCIENCE. By P. G. TAIT, M.A. London: Macmillan & Co. For sale by Van Nostrand. Price $2.50.

Nothing is more acceptable to the lover of science and scientific literature than an occasional summary of scientific discoveries, provided always that such a summary is prepared by competent hands. Such is the present book by Prof. Tait.

The lectures bear the following titles: 1, Introductory; 2, Early History of Energy; 3, Establishment of the Conservation of Energy; 4, Transformation of Energy; 5, Transformation of Heat into Work; 6, Transformation of Energy; 7, Sources and Transference of Energy; 8, Radiation and Absorption; 9, Spectrum Analysis; 10, Spectrum Analysis; 11, Conduction of Heat; 12 and 13, Structure of Matter.

The typography is good, and the few illustrations are of fair quality.

ANNUAL REPORT OF THE CHIEF SIGNAL OFFICER TO THE SECRETARY OF WAR FOR THE YEAR 1875. Washington: Government Printing Office.

Whoever takes pride in the establishment of the Signal Bureau of the United States should become possesssor of the voluminous report for 1875. He can then justify his patriotic feeling by ready reference to the printed record.

We rejoice in the fact that the Bureau has become so firmly established, that its continuance is no more a question than that of the ready distribution of the mails. The management has been from the first in the most thoroughly competent hands. Only a few years since such a department was not in existence, and its uses were not dreamed of by the general public; now we have the most efficient system of observation and report known to the world, and the advantages are warmly acknowledged by all who read the daily papers. We doubt not the public voice would favor any extension of the system that its director deems desirable; it would thereby do justice to an efficient public officer.

TRAITE PRATIQUE DU CHAUFFAGE PAR LE GAZ. Par GUSTAVE GERMINET. Paris: Eugéne Lacroix. For sale by Van Nostrand. Price $1.00.

This contains brief but lucid descriptions of the various pieces of mechanism employed when the combustion of gas is made to play an important part in many industrial operations.

Besides the little heaters for warming or cooking, which are well known here, several modifications of the compound blow pipe are described, which are used for soldering, brazing and other common operations of the mechanics' shops.

LIGHT AS A MOTIVE POWER: A SERIES OF HYDROGRAPHICAL ESSAYS. By Lieut. R. H. ARMIT, R. N. 2 vols. 8vo. London: Trubner & Co. For sale by D. Van Nostrand. Price $15.00.

In glancing over the second volume of these essays (the first has been published some time) we are constrained to sympathize with the reviewer of the first volume who declined to follow where the author would lead.

In the few places where the author, by the proper use of scientific terms, has expressed an opinion upon oceanic or atmospheric circulation, we have no hesitation in rejecting his conclusions. But we confess to have felt a certain degree of interest in the more numerous passages where acknowledged facts and familiar terms are misused—that kind of interest which one feels in mild forms of conundrum. But this interest is not sustained for the reason that there is no known solution of the conundrums.

We offer a few samples from the second volume. If the reader enjoys them he will be satisfied to know there is plenty of them in the same book.

The author begins to "sum up" on page 213 in the following terms:

"And we hold that we have established the *unity* of the following points:

"1. That electricity is that fluid which, under different names, be it galvanism, magnetism, electro-galvanism, or electro-magnetism, binds the whole universe together and exerts that force which science calls gravity.

"2. That electricity is *Light*, *Heat* and *Cold*, and is therefore one body divided into three substances, and that all these are *Motive Forces*.

"3. That heat, light and cold are *Life*.

"4. That some obscure process of evaporation is continually going on throughout the mineral formation of the globe—we might say of the universe," etc., etc.

It makes but little difference where we stop, as the object is merely to offer a fair sample of the book.

MISCELLANEOUS.

IT is stated in a Vienna telegram that in order to obtain the means for providing new artillery for the army a loan is in contemplation, contracted jointly by both halves of the empire. By this course it would be possible thoroughly to re-equip the artillery regiments at once, and to distribute the cost over a lengthened period.